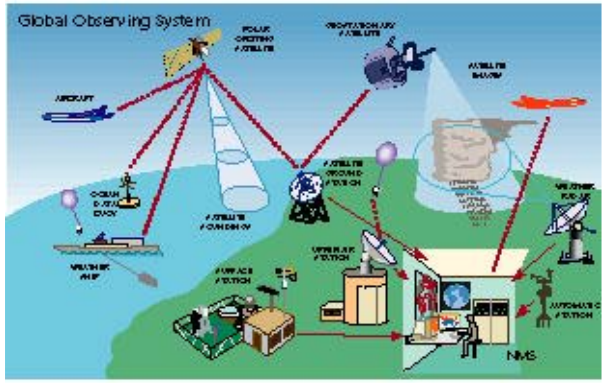
Prospettive della Modellistica Previsionale ad Area Limitata

Tiziana Paccagnella

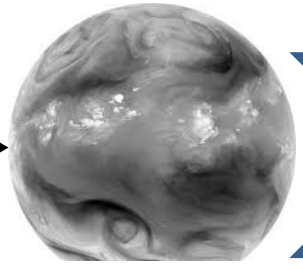
arpae
agenzia prevenzione ambiente energia emilia-romagna

Modellistica numerica previsionale

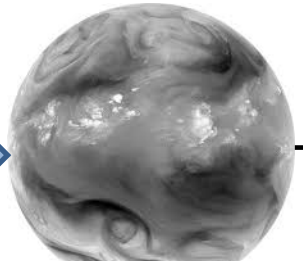
Assimilazione dati meteorologici



Processo che, in base alle osservazioni e….. cerca di definire uno stato coerente dell'atmosfera idoneo ad inizializzare un modello numerico



Modello numerico previsionale

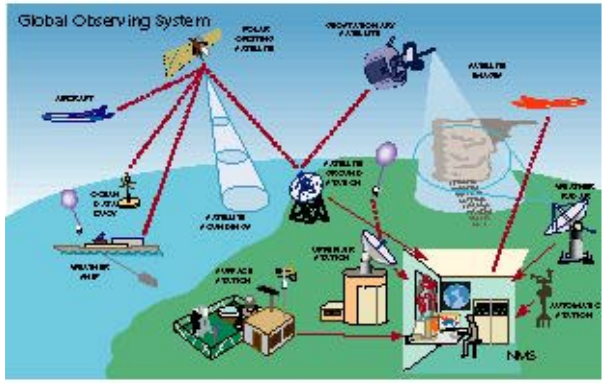


Stato "attuale" dell'atmosfera

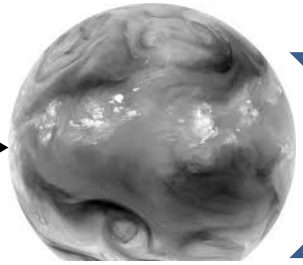
Stato futuro dell'atmosfera

Modellistica numerica previsionale

Assimilazione dati meteorologici

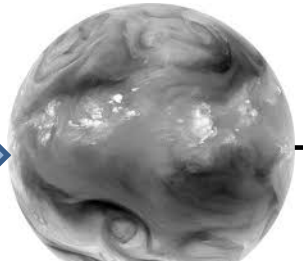


Processo che, in base alle osservazioni e….. cerca di definire uno stato coerente dell'atmosfera idoneo ad inizializzare un modello numerico



Stato "attuale" dell'atmosfera

Modello numerico previsionale



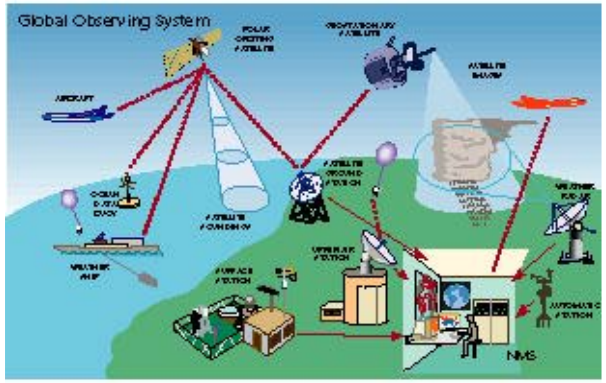
Stato futuro dell'atmosfera

Verifica Validazione

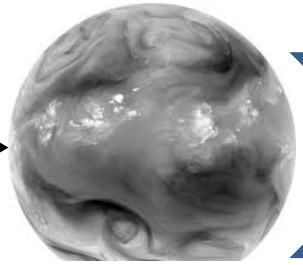
Post-Processing

Modellistica numerica previsionale

Assimilazione dati meteorologici

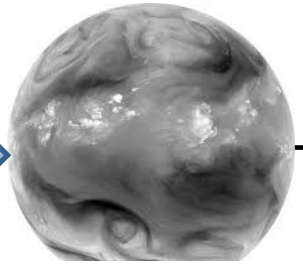


Processo che, in base alle osservazioni e….. cerca di definire uno stato coerente dell'atmosfera idoneo ad inizializzare un modello numerico



Stato "attuale" dell'atmosfera

Modello numerico previsionale



Stato futuro dell'atmosfera

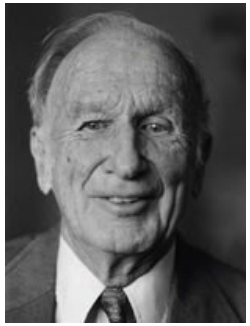
Verifica Validazione

Post-Processing

P R O D O T T I

Even if NWP has started based on a deterministic approach, Edward Lorenz , the father of chaos theory, showed as the error growth set a finite limit to the predictability of the state of the atmosphere.

The Atmosphere is a chaotic system



arpae
agenzia prevenzione ambiente energia emilia-romagna

L'atmosfera
è un sistema caotico

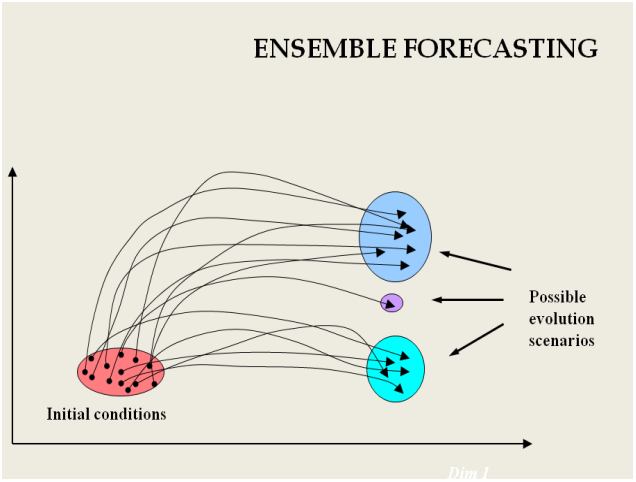
La ricerca inerente lo studio del limite della predicibilità deterministica ha portato ad un approccio combinato di determinismo e probabilismo….

L'ENSEMBLE PREDICTION

Model Errors

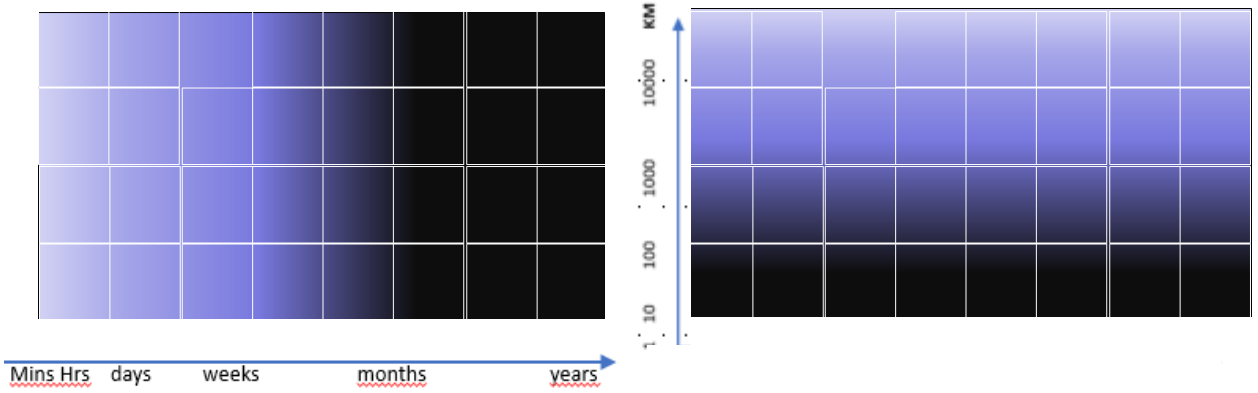
Accounting for uncertainties associated to Numerical Forecast

Analysis Errors



High Predictability

Low/No Predictability



La «Predictability» diminuisce all'aumentare della scadenza previsionale ma anche in relazione ad eventi a piccola scala (localizzazione nello spazio e nel tempo)

POWER SPECTRUM OF HORIZONTAL WIND SPEED IN THE FREQUENCY RANGE FROM 0.0007 TO 900 CYCLES PER HOUR

By Isaac Van der Hoven

U. S. Weather Bureau[1]

(Manuscript received 11 October 1956)

Predictability depends on spatial and temporal scales of atmospheric phenomena

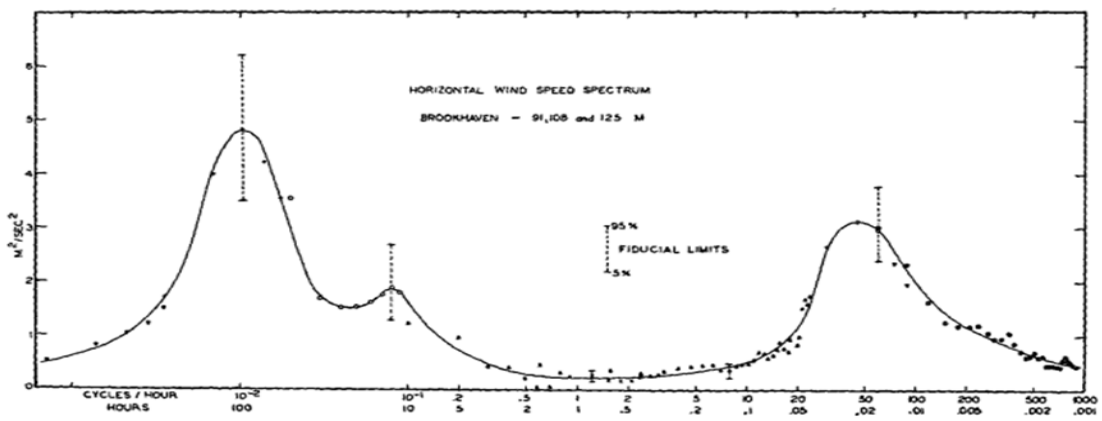
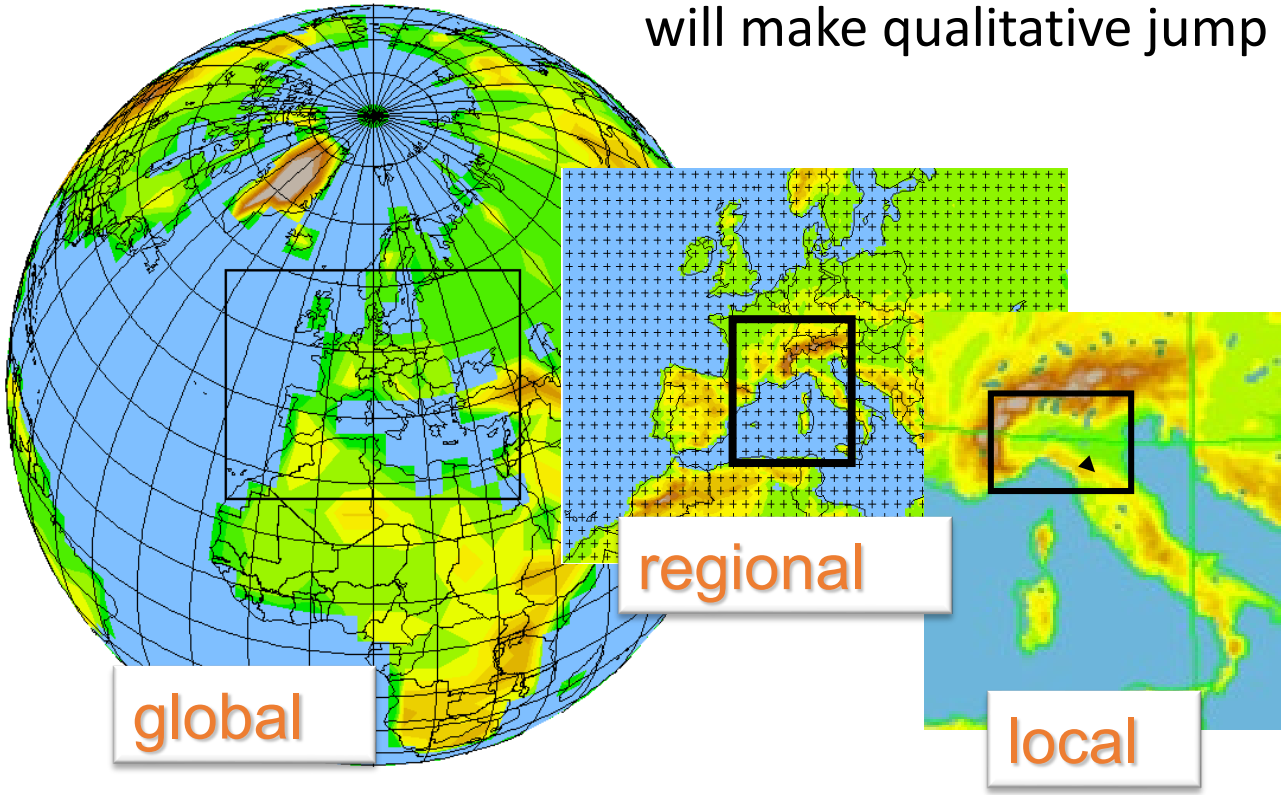
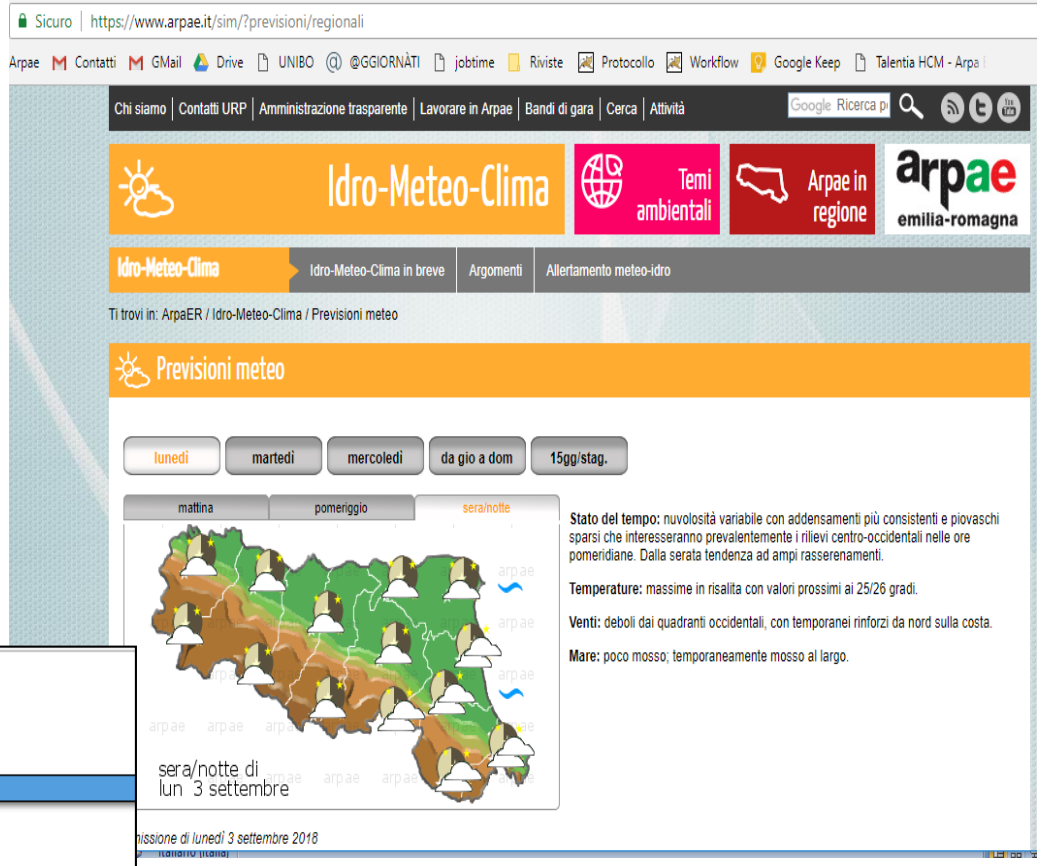


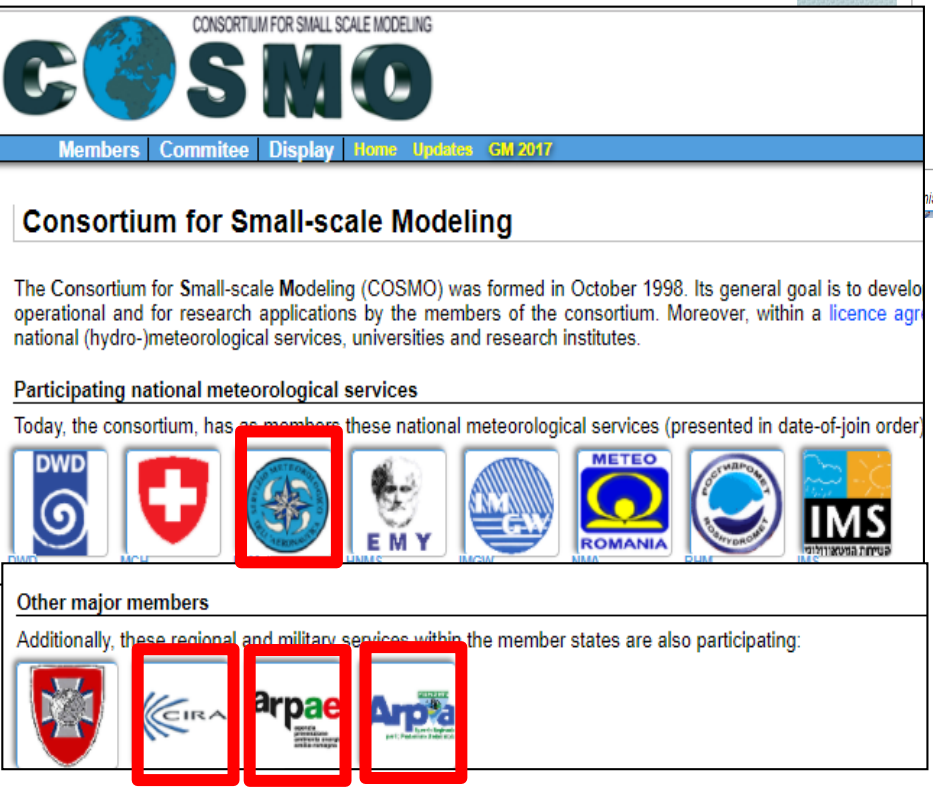
FIG. 1. Horizontal wind-speed spectrum at Brookhaven National Laboratory at about 100-m height. (See table 1 for date and time.)

Science community agrees that at very high resolution models will make qualitative jump in accuracy



NWP Numerical Weather Prediction @ARPAE-SIMC



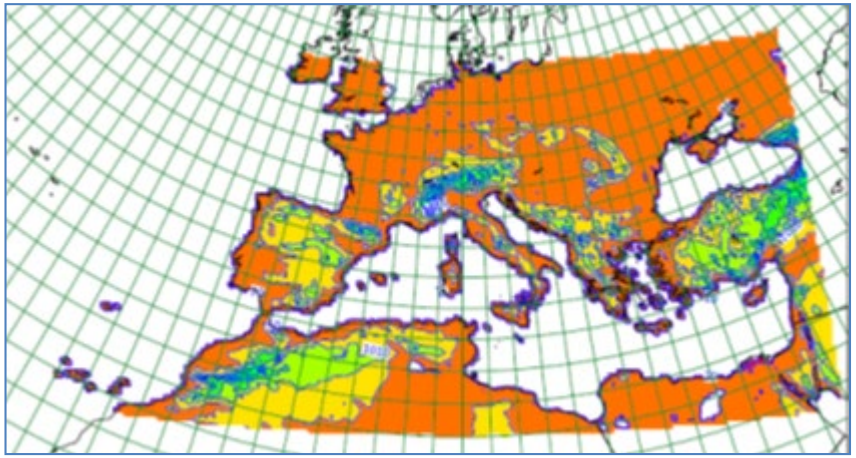


Italy is part of the International European Consortium COSMO LAMI Agreement for National cooperation

arpae agenzia prevenzione ambiente energia emilia-romagna

LAMI operational suites implemented and managed by ARPAE-SIMC
with funds from National Dept. Of Civil Protection

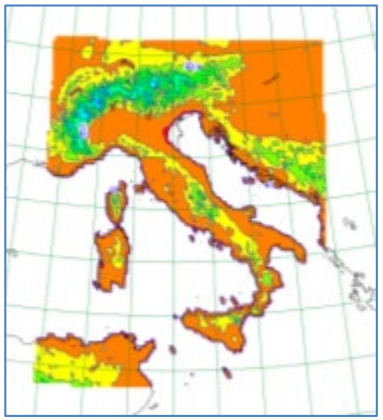
COSMO 5M
5 km h.r.



BCs from ECMWF IFS
IC from AM-Rome LETKF analysis

Two runs per day +72

COSMO 2I
2.2 km h.r.



BCs from COSMO 5M
IC from the new LETKF by ARPAE SIMC

Two runs per day +48
and
Eight runs per day +18
(Rapid Update Cycle)

Davide Cesari, Paolo Patruno, Gianfranco Marras, Daniele Branchini, Emanuele di Giacomo

arpae
agenzia prevenzione ambiente energia emilia-romagna

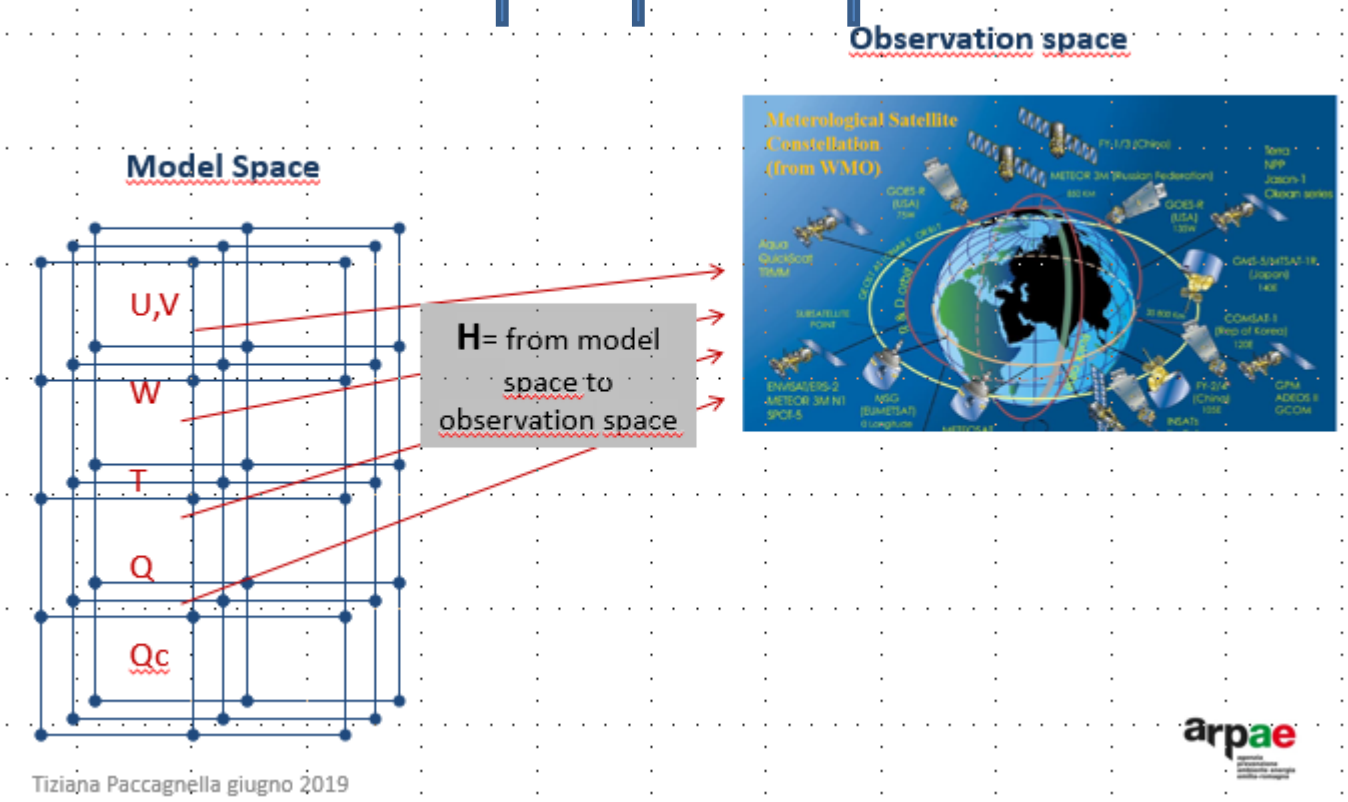
Data assimilation

H= from model space to observation space

M= NWP model

$$x_a = x_b + \boldsymbol{K}(y - \boldsymbol{H}x_b)$$

$$\boldsymbol{K} = \boldsymbol{B}\boldsymbol{H}^{\mathrm{T}}\left[\boldsymbol{H}\boldsymbol{B}\boldsymbol{H}^{\mathrm{T}} + \boldsymbol{R}\right]^{-1}$$



Data assimilation

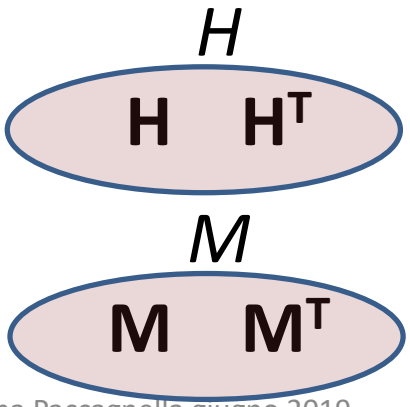
H= from model space to observation space

M= NWP model

$$x_a = x_b + \boldsymbol{K}(y - \boldsymbol{H}x_b)$$

$$\boldsymbol{K} = \boldsymbol{B}\boldsymbol{H}^{\mathrm{T}}\left[\boldsymbol{H}\boldsymbol{B}\boldsymbol{H}^{\mathrm{T}} + \boldsymbol{R}\right]^{-1}$$

Analisi variazionale (B climatologica)	Sistemi ibridi	Ensemble Based Systems (B flow dependent)



H

M

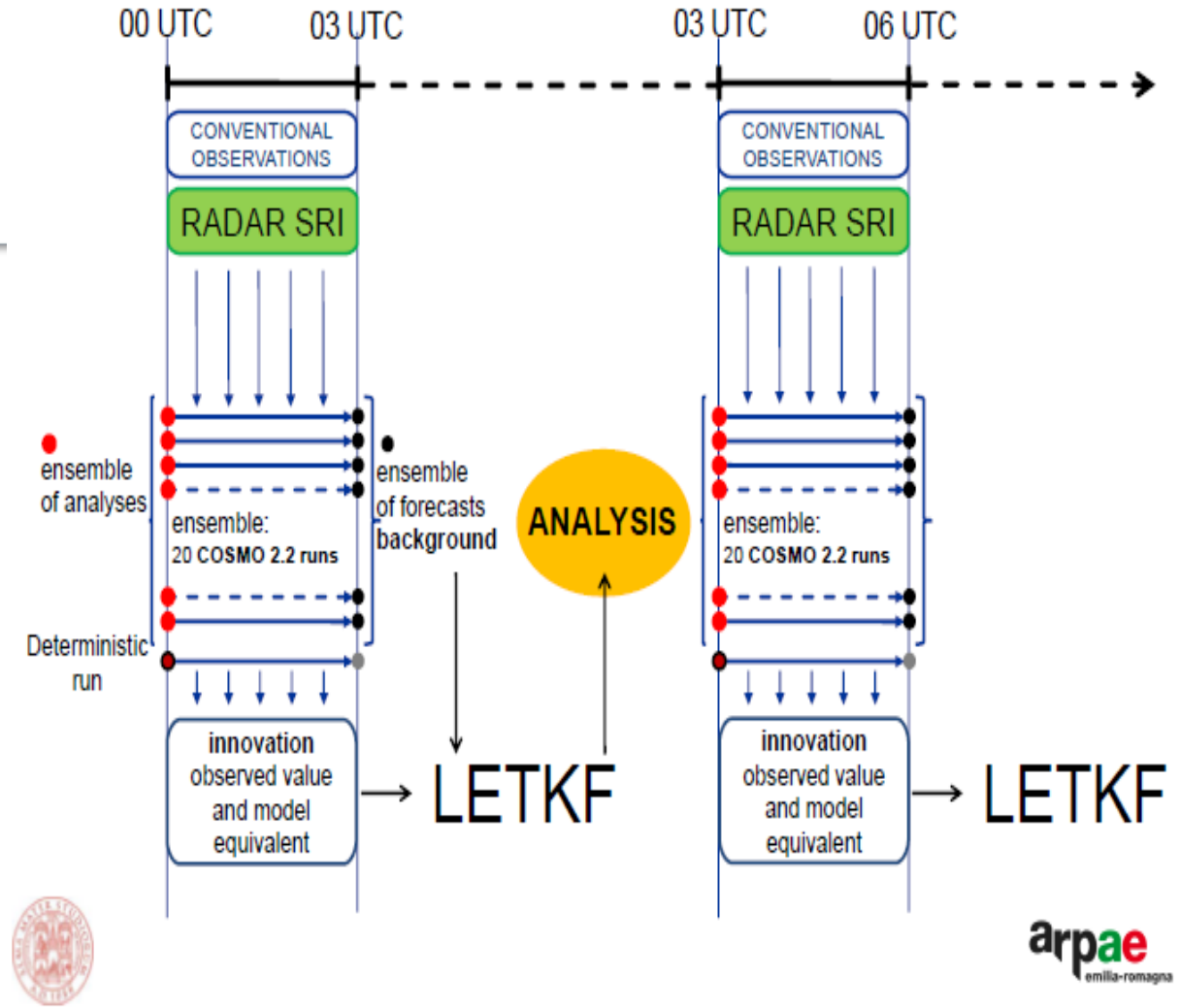
arpae agenzia prevenzione ambiente energia emilia-romagna

Impact of the observational erro in the assimilation of radar reflectivity volumes

Thomas Gastaldo, Virginia Poli, Chiara Marsigli
Tiziana Paccagnella, Pier Paolo Alberoni

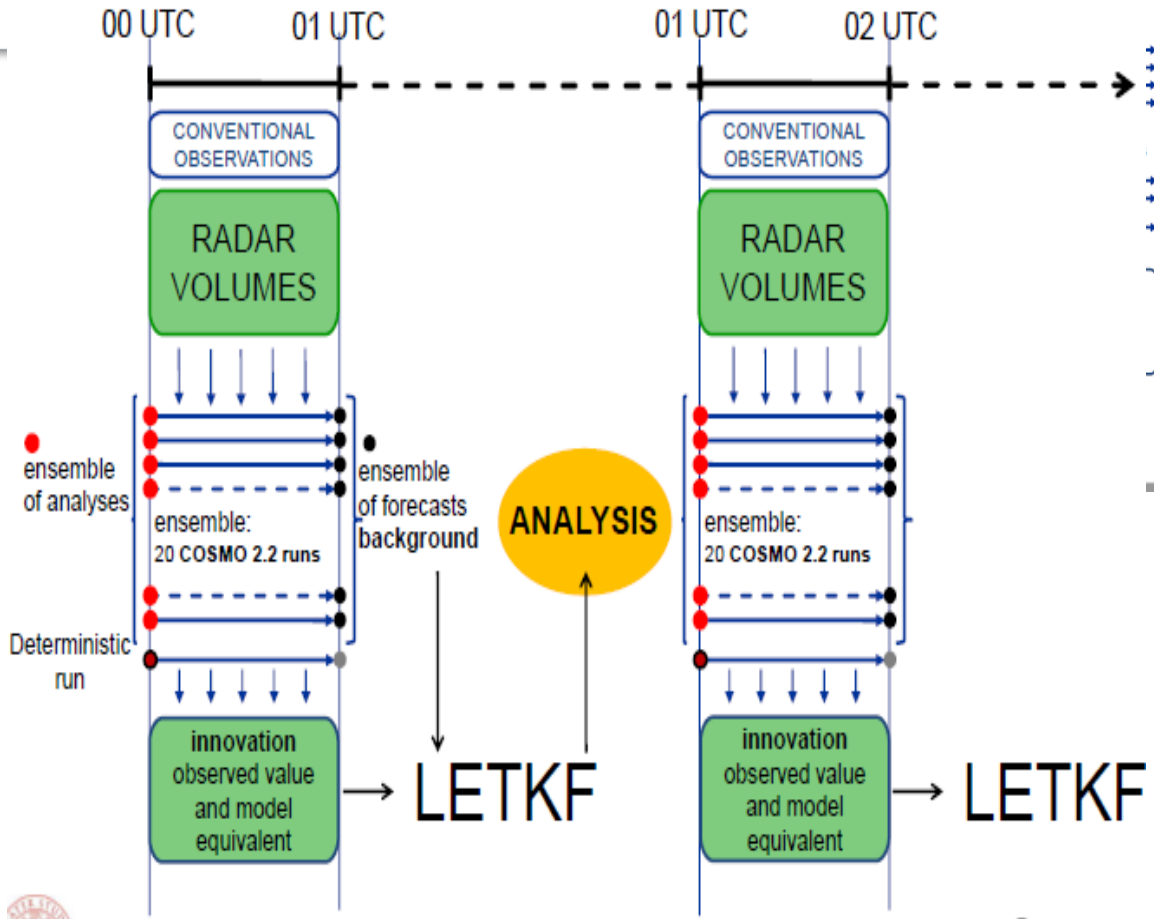
The 8th EnKF Data Assimilation Workshop

KENDA – Operational set-up

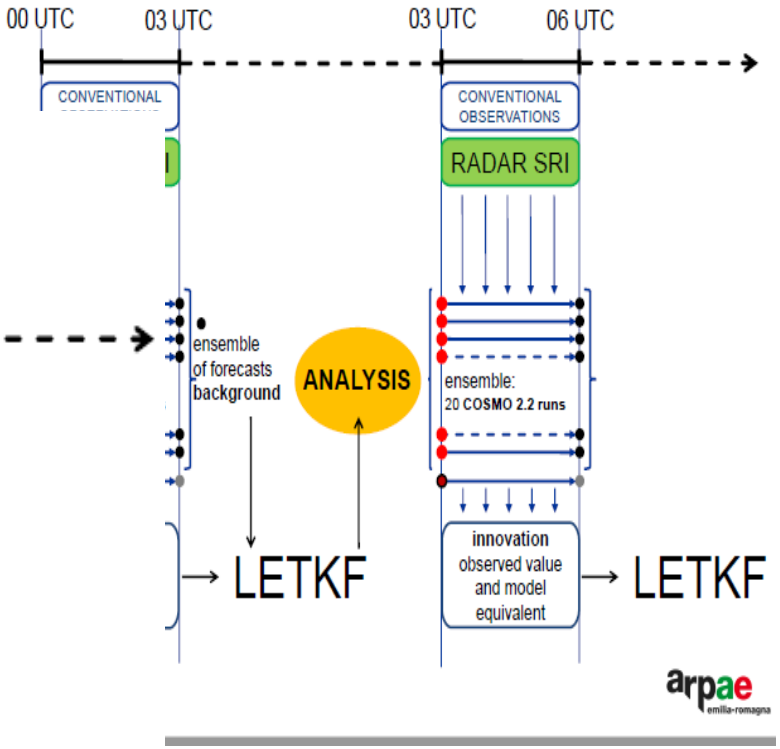


Impact of the observational error in the assimilation of radar reflectivity volumes

KENDA – Experimental set-up



KENDA – Operational set-up



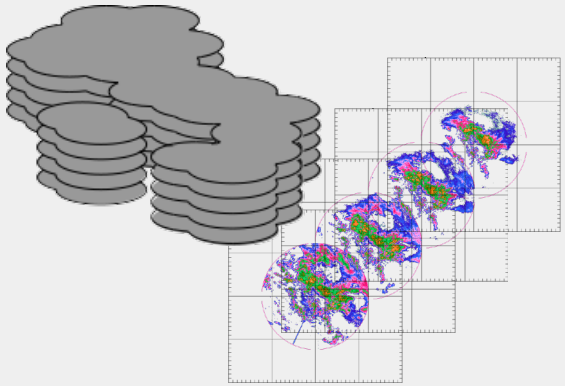
arpae emilia-romagna

arpae agenzia prevenzione ambiente energia emilia-romagna

Assimilazione dei dati radar

OSSERVAZIONI

Volumi di riflettività della rete radar nazionale



COSMO

INPUT

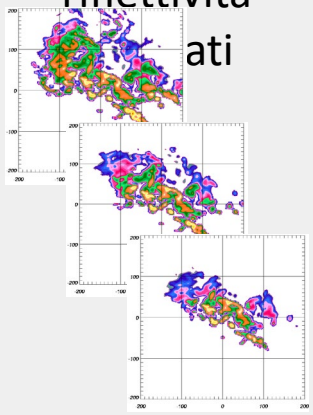
Campi delle variabili prognostiche del modello

OPERATORE

Efficient Modular VOlume RADar Operator (EMVORADO)

OUTPUT

Volumi di riflettività ati



SISTEMA DI ASSIMILAZIONE DATI

Kilometer ENsemble Data Assimilation (KENDA) basato su un Local Ensemble Transform Kalman Filter

V.Poli, T.Gastaldo, C.Marsigli, T.Paccagnella

Calibrazione del sistema di assimilazione

A livello operativo, l'assimilazione di volumi di riflettività radar mediante un metodo di Ensemble Kalman Filter (EnKF) è ancora **pionieristico**. Pertanto, è stato necessario effettuare numerosi test per calibrare il sistema, in particolare in relazione a:

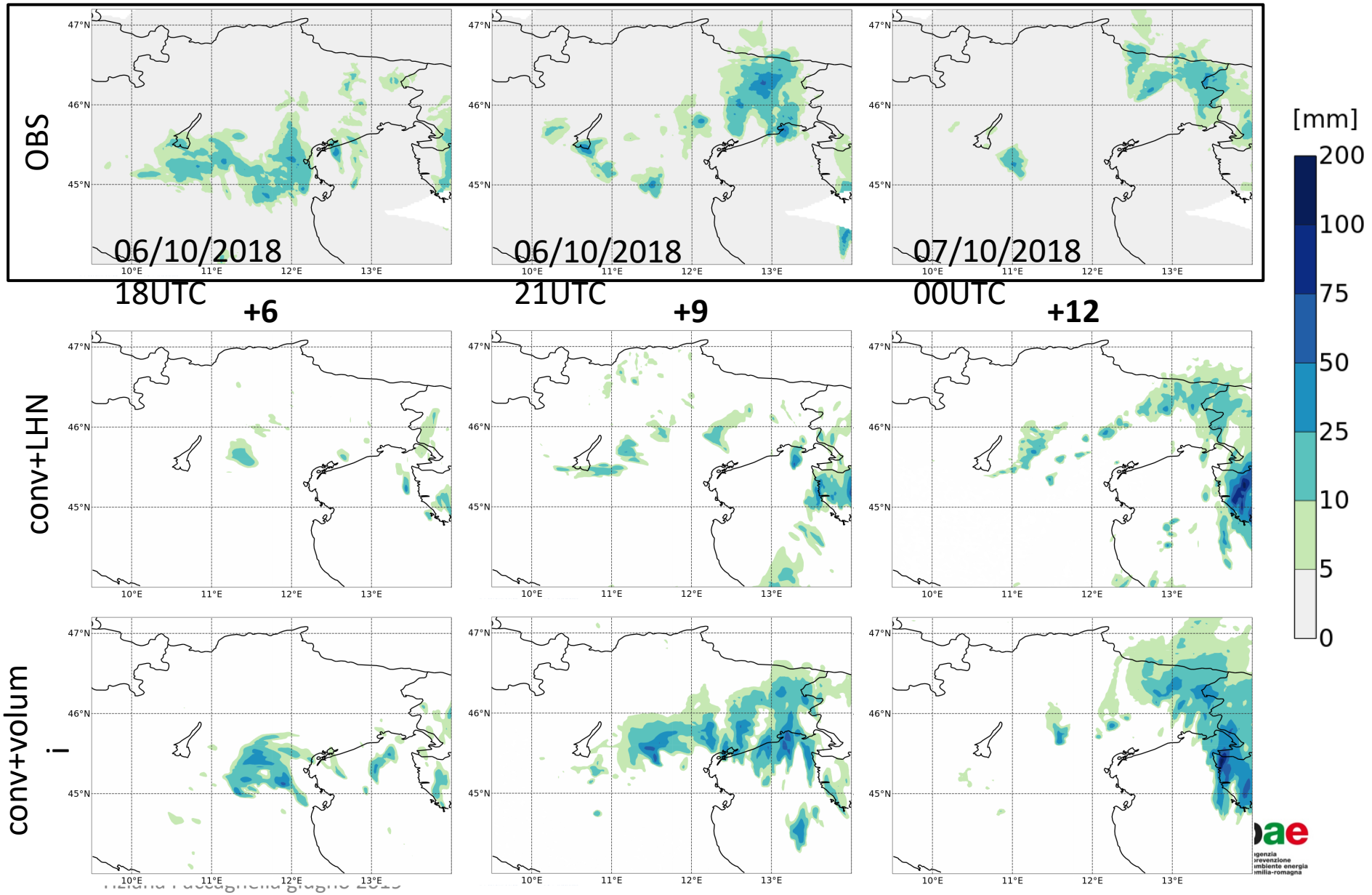
- pre-processing del dato in input (**superobbing**);
- **lunghezza dei cicli** di assimilazione e conseguente instabilità;
- matrice di covarianza degli **errori osservativi**;
- specifiche **operatore radar** (tipo di scattering, attenuazione…);
- **perturbazioni** della fisica e metodi di inflation per aumentare lo spread dell'ensemble.

[POSTER] Virginia Poli, Thomas Gastaldo, Chiara Marsigli, Pier Paolo Alberoni, Tiziana Paccagnella , Arpae - Struttura Idro-Meteo-Clima, Bologna

Assimilazione dei volumi di riflettività radar nel modello COSMO

V.Poli, T.Gastaldo, C.Marsigli, T.Paccagnella

Previsione del 06/10/2018 alle 12:00

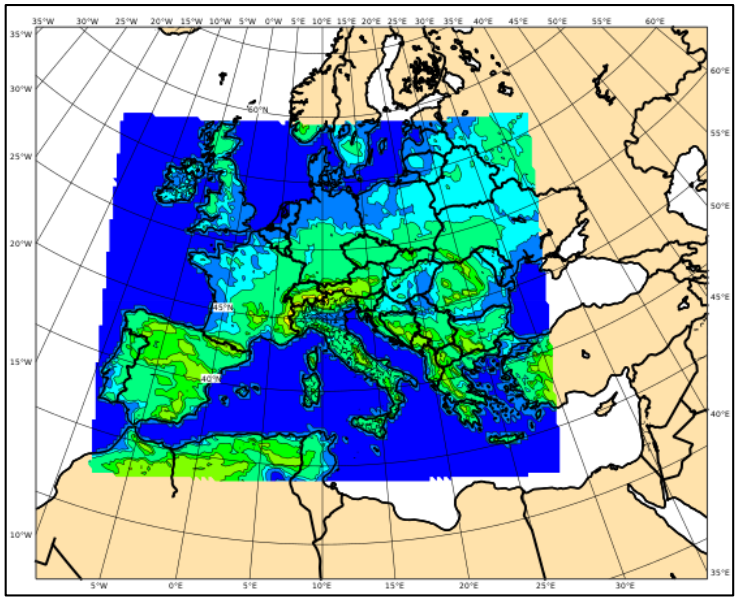


Ensemble Systems @ ARPAE-SIMC:

COSMO-LEPS by ARPAE SIMC for the COSMO Consortium

ECMWF EPS
Initial and boundary conditions

20 members, 7(5) km H.R.
2 runs per day +120



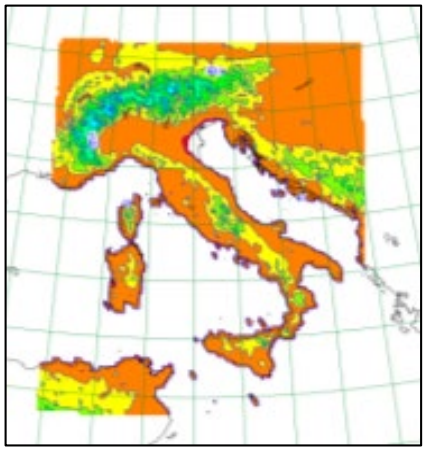
Andrea Montani, Ines Cerenzia

ARPAE SIMC COSMO 2I EPS Pre-operational

ECMWF EPS
Initial and boundary conditions

COMET Rome EPS
boundary conditions

20 members, 2.2 km H.R.
1 run per day +48



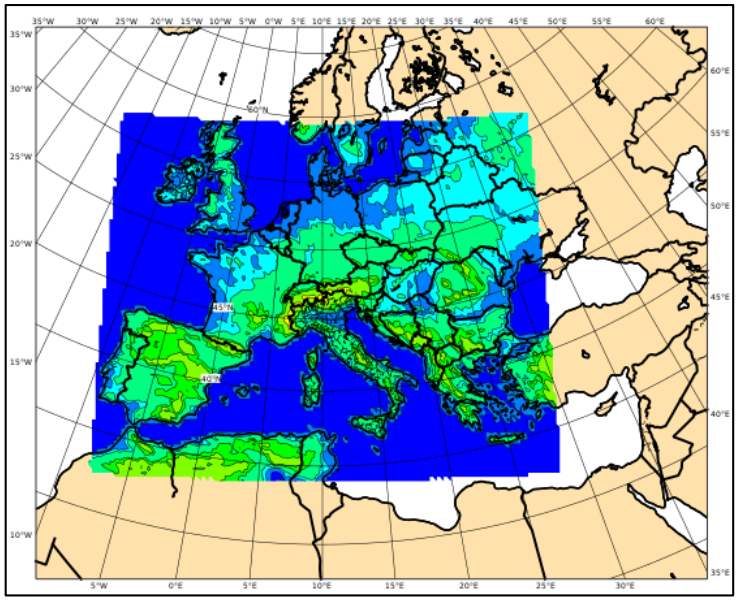
Davide Cesari, Paolo Patruno, Gianfranco Marras, Daniele Branchini, Emanuele di Giacomo

Ensemble Systems @ ARPAE-SIMC:

COSMO-LEPS by ARPAE SIMC for the COSMO Consortium

ECMWF EPS
Initial and boundary conditions

20 members, 7(5) km H.R.
2 runs per day +120

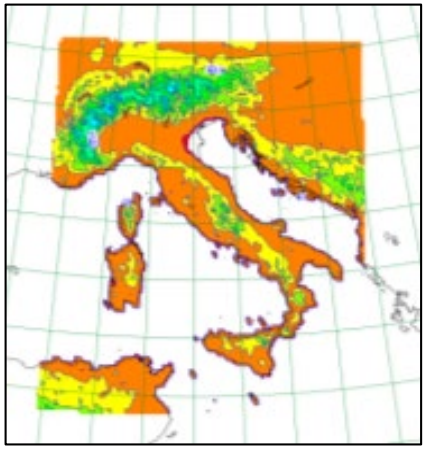


ARPAE SIMC COSMO 2I EPS Pre-operational

ECMWF EPS
Initial and boundary conditions

COMET Rome EPS
boundary conditions

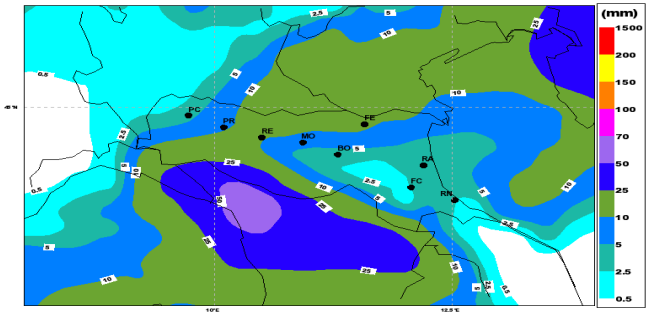
20 members, 2.2 km H.R.
1 run per day +48



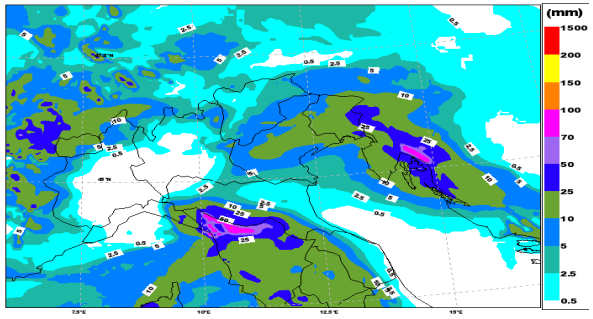
[POSTER] Pincini G., Montani A., Paccagnella T., Tesini M.S., Cerenzia I., Marsigli C.
Arpae - SIMC, Bologna, »Previsione di eventi meteo ad elevato impatto sull'Italia: performance di Ens emble Prediction Systems globali e ad area limitata»

At higher resolution, model structures are stronger and better defined; thus even small timing and placement errors produce substantial forecast errors

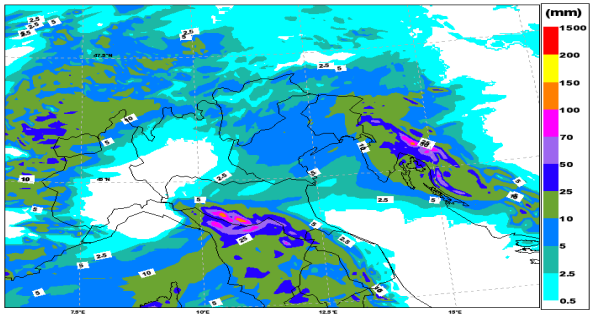
(**Mass et al., 2002 "**Does increasing horizontal resolution produce mode skillful forecasts?")



ECMWF
ris.orizz: 16 km



COSMO-I7
ris.orizz: 7 km



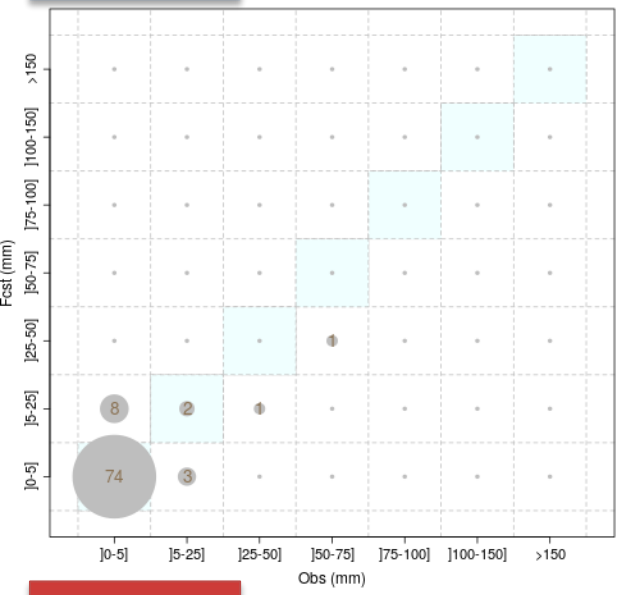
COSMO-I2
ris.orizz: 2.8 km

arpae
agenzia prevenzione ambiente energia emilia-romagna

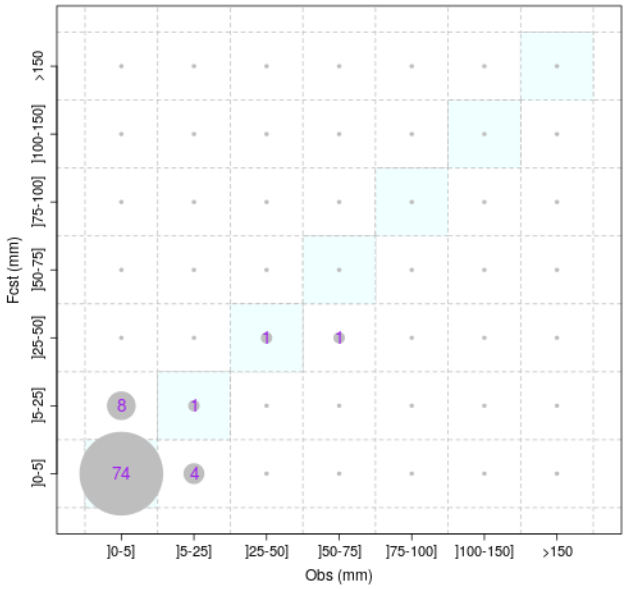
VERIFICA SU MACROAREE – DJF2018-19 - precipitazione cumulata in 24 ore alla scadenza +48h

MEDIA

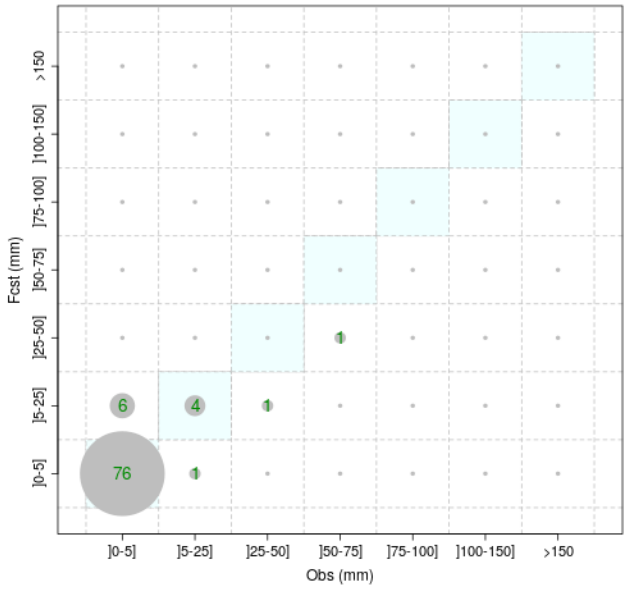
COSMO-2I



COSMO-5M

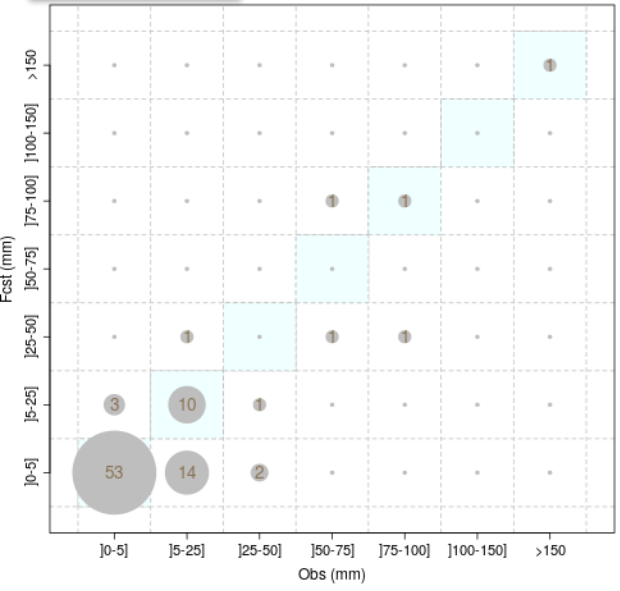


IFS-ECMWF

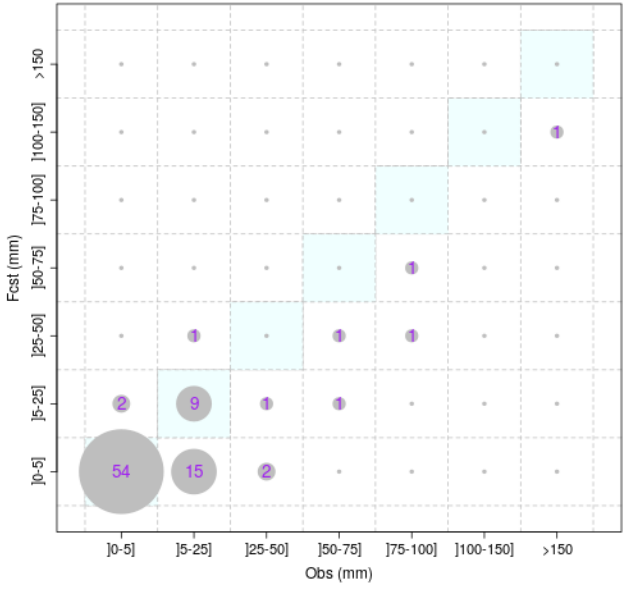


MAX

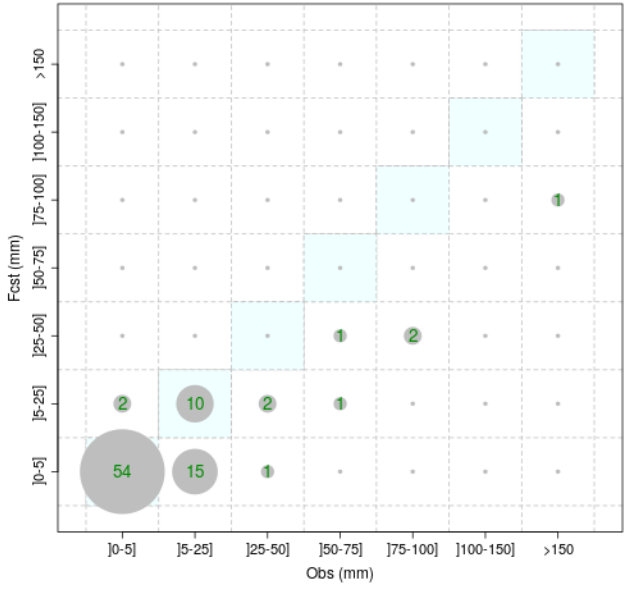
COSMO-2I



COSMO-5M

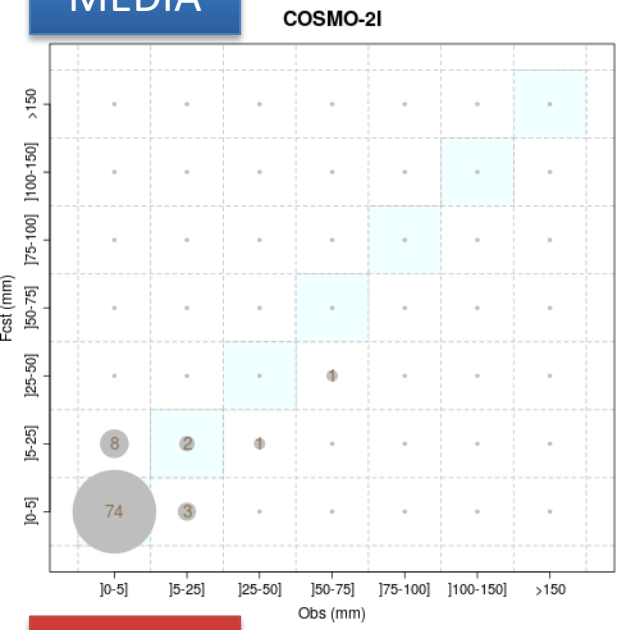


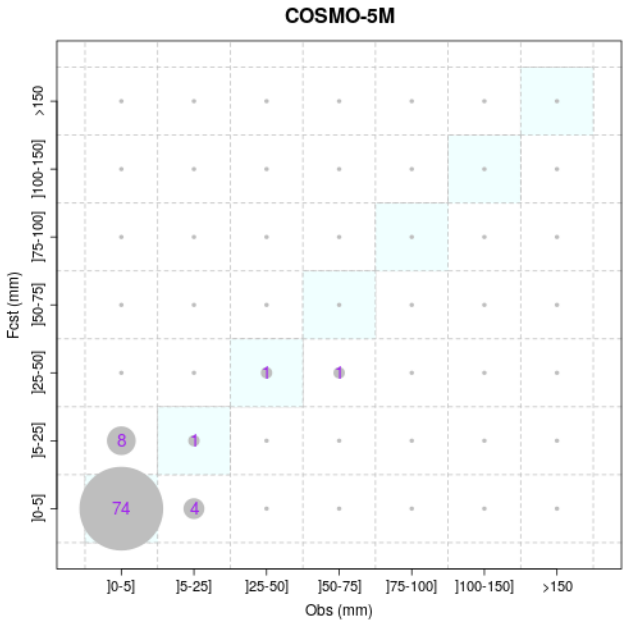
IFS-ECMWF

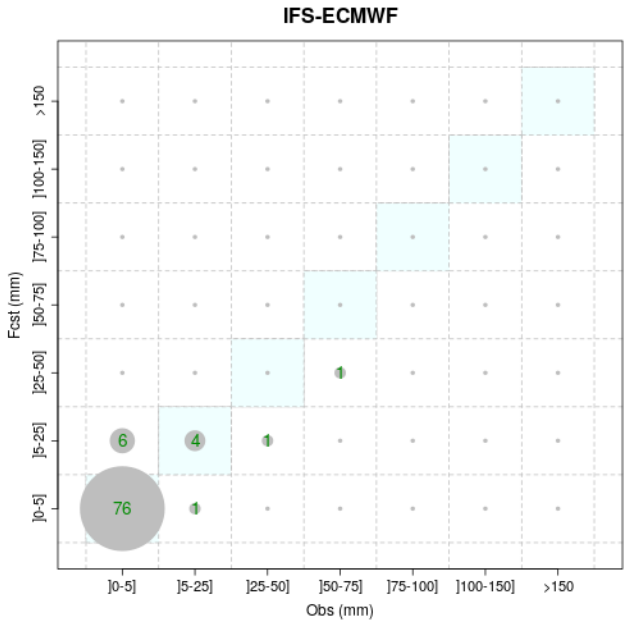


VERIFICA SU MACROAREE – DJF2018-19 - precipitazione cumulata in 24 ore alla scadenza +48h

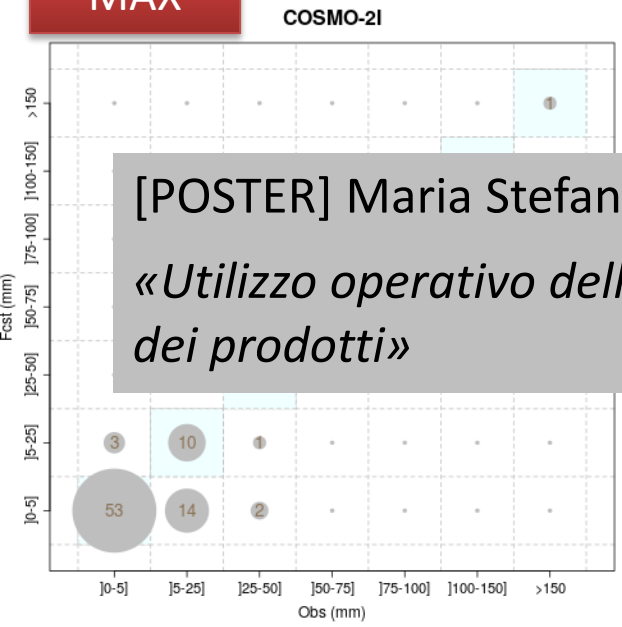
MEDIA

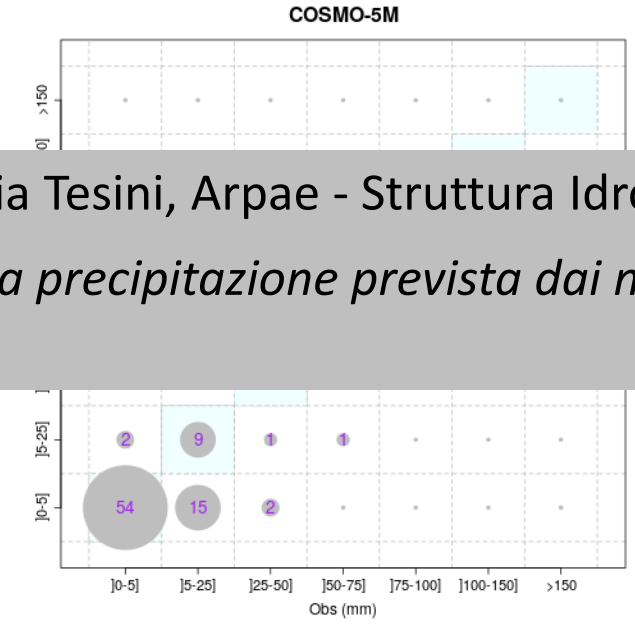


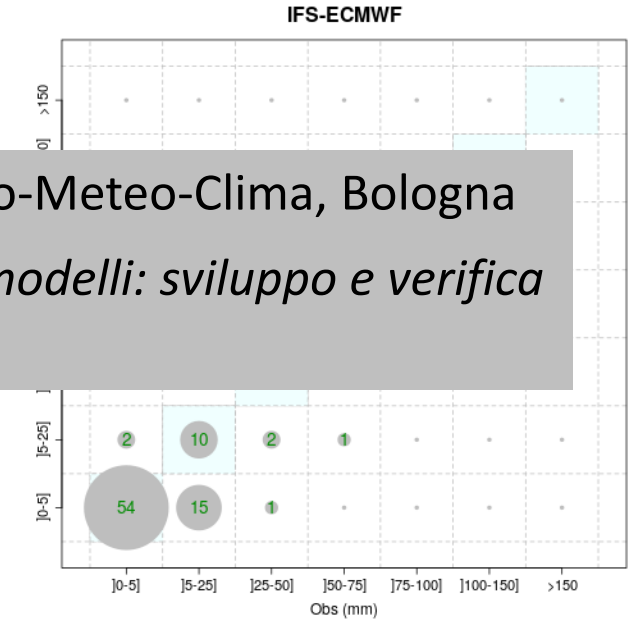




MAX





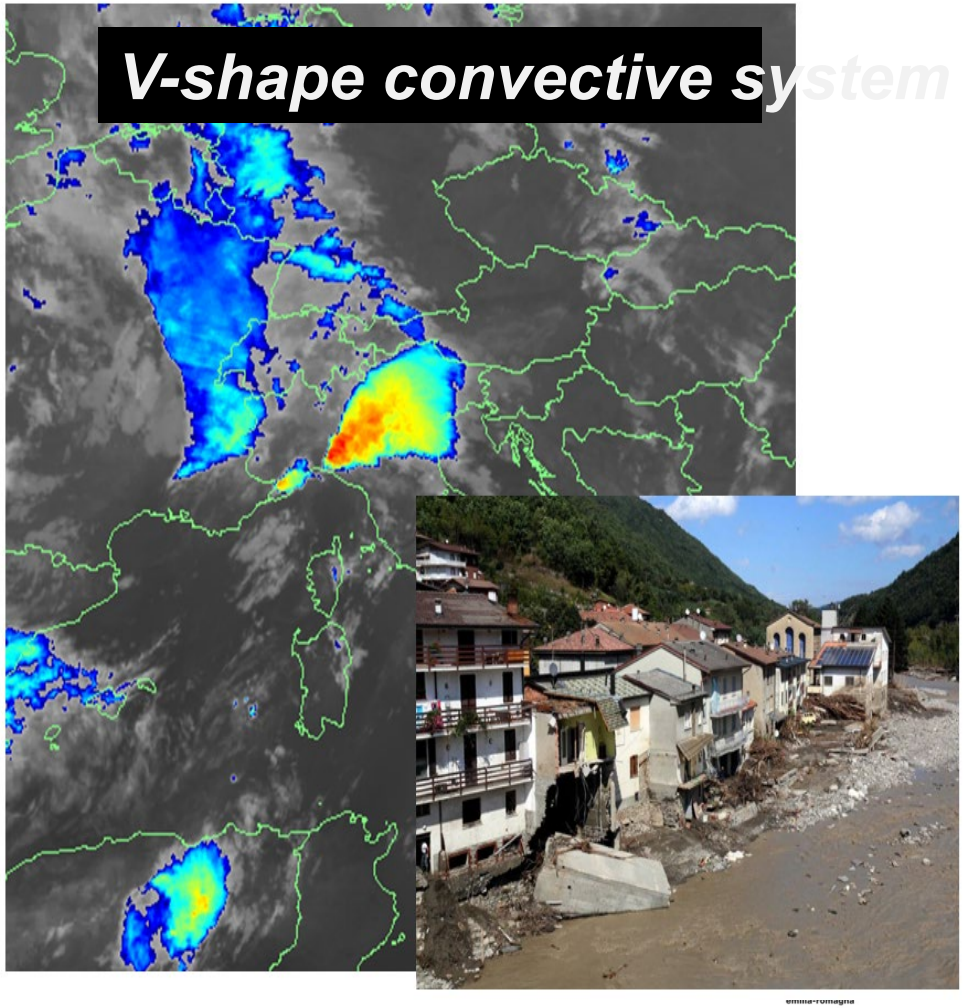


[POSTER] Maria Stefania Tesini, Arpae - Struttura Idro-Meteo-Clima, Bologna

«Utilizzo operativo della precipitazione prevista dai modelli: sviluppo e verifica dei prodotti»

Secchia Flood

Piacenza flood: 13-14/9/2015



Genova
9-10 October 2014

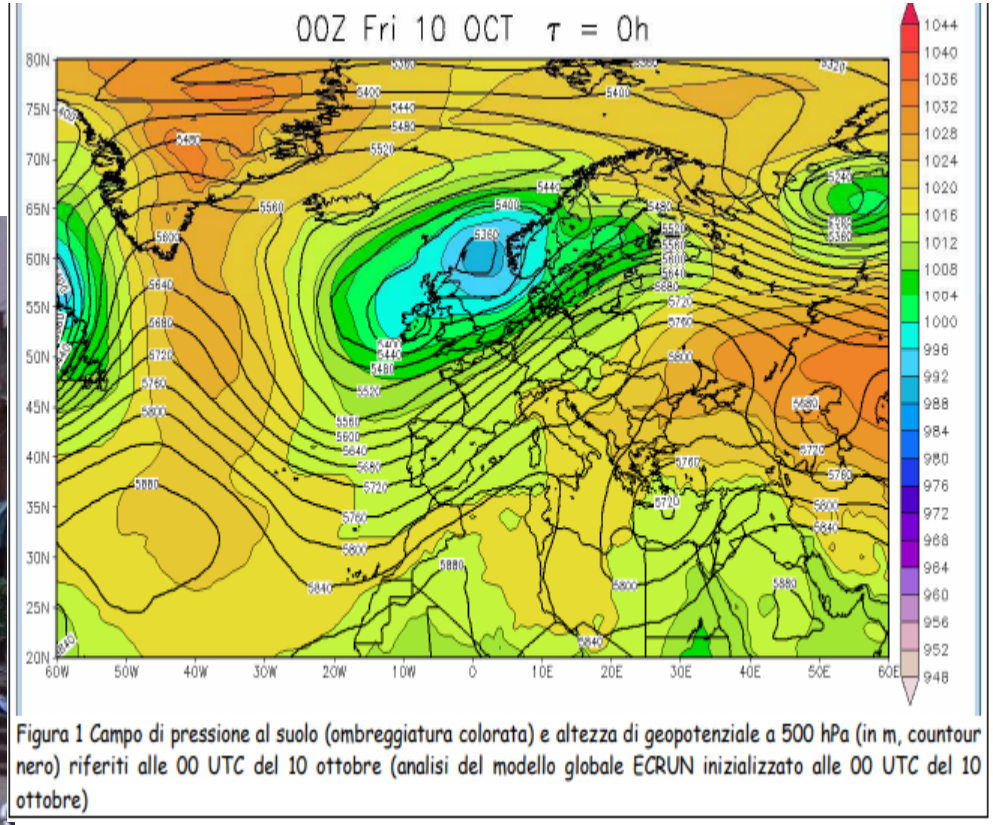
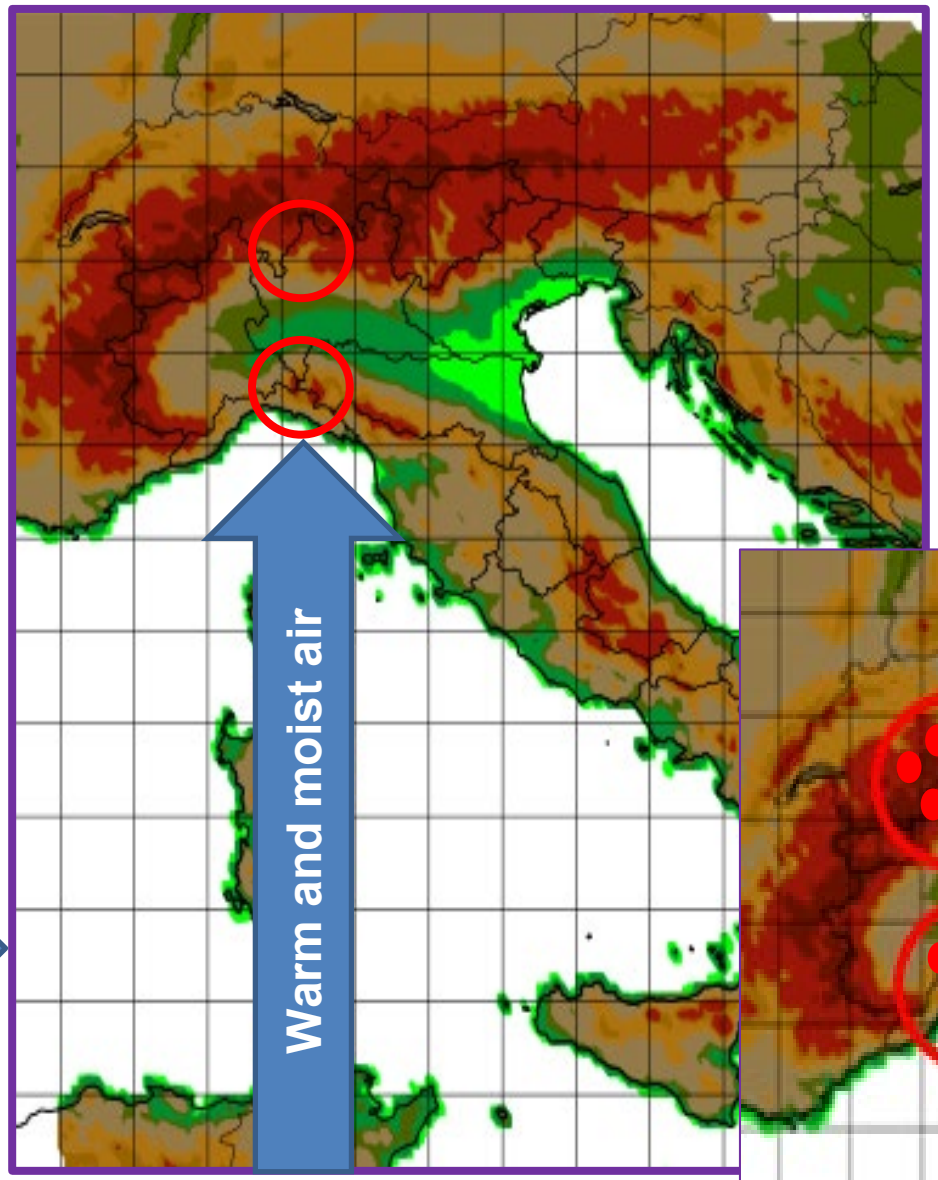


Figura 1 Campo di pressione al suolo (ombreggiatura colorata) e altezza di geopotenziale a 500 hPa (in m, countour nero) riferiti alle 00 UTC del 10 ottobre (analisi del modello globale ECRUN inizializzato alle 00 UTC del 10 ottobre)

arpae
agenzia prevenzione ambiente energia emilia-romagna

Predictability

Precipittion due to orographic uplift

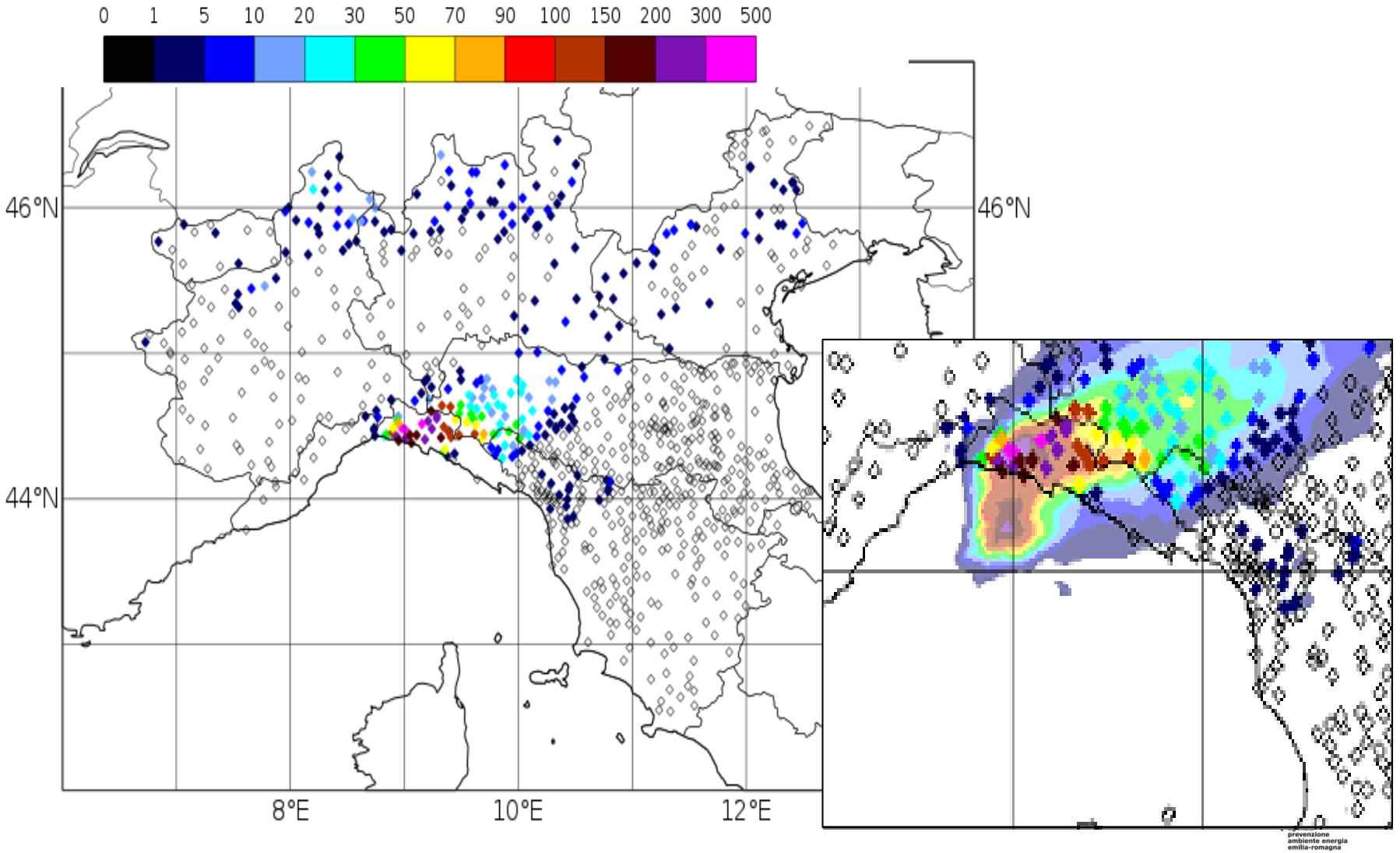


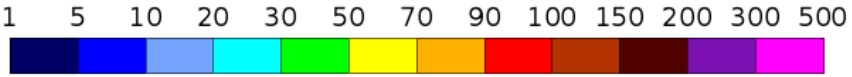
Where and when these maxima will occurr?

Very small basins with a very short time of concentrati on

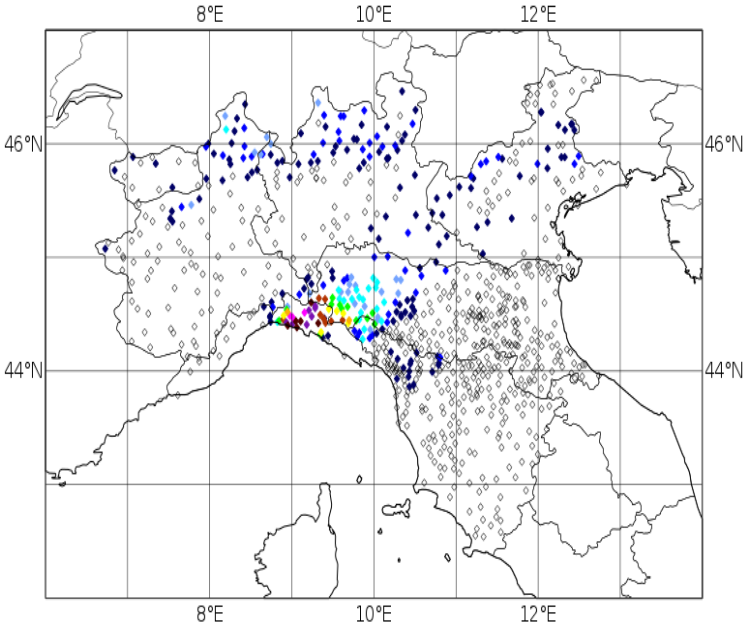
24h accumulated observed precipitation

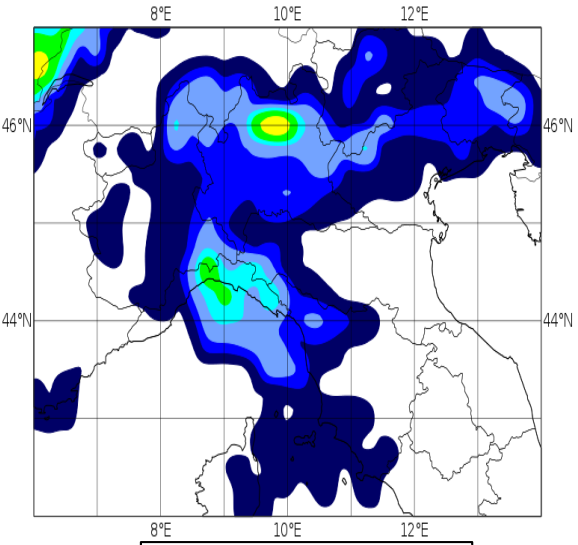
09/10/14 12 UTC – 10/10/14 12 UTC



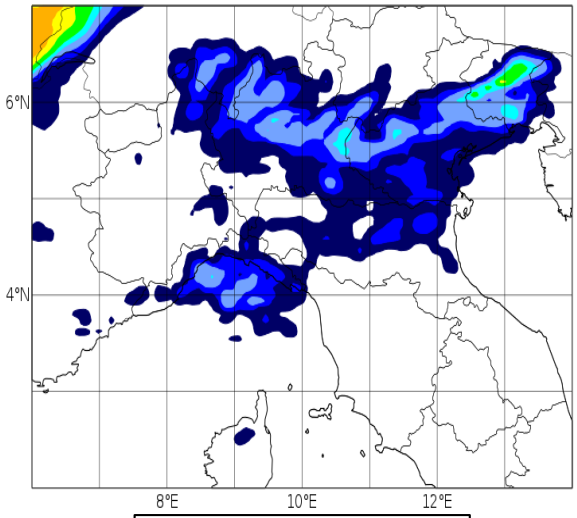


+ 00 24

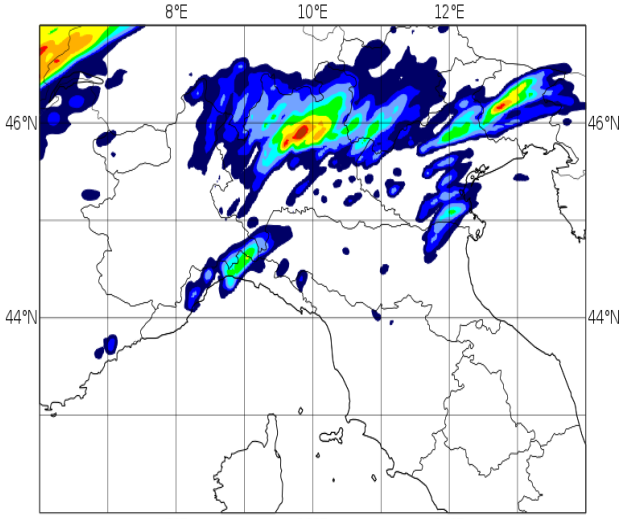




ECMWF IFS



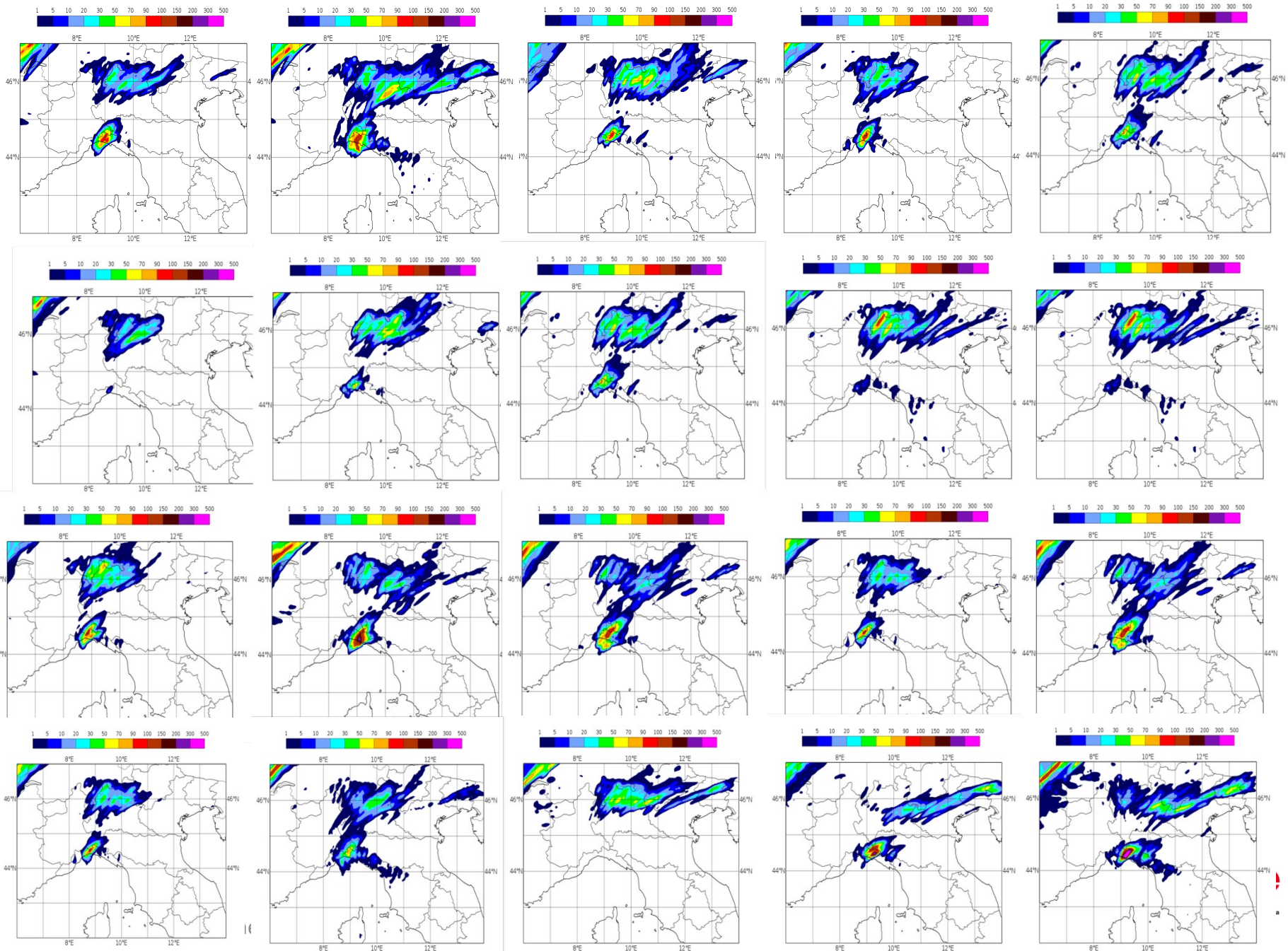
COSMO 7km



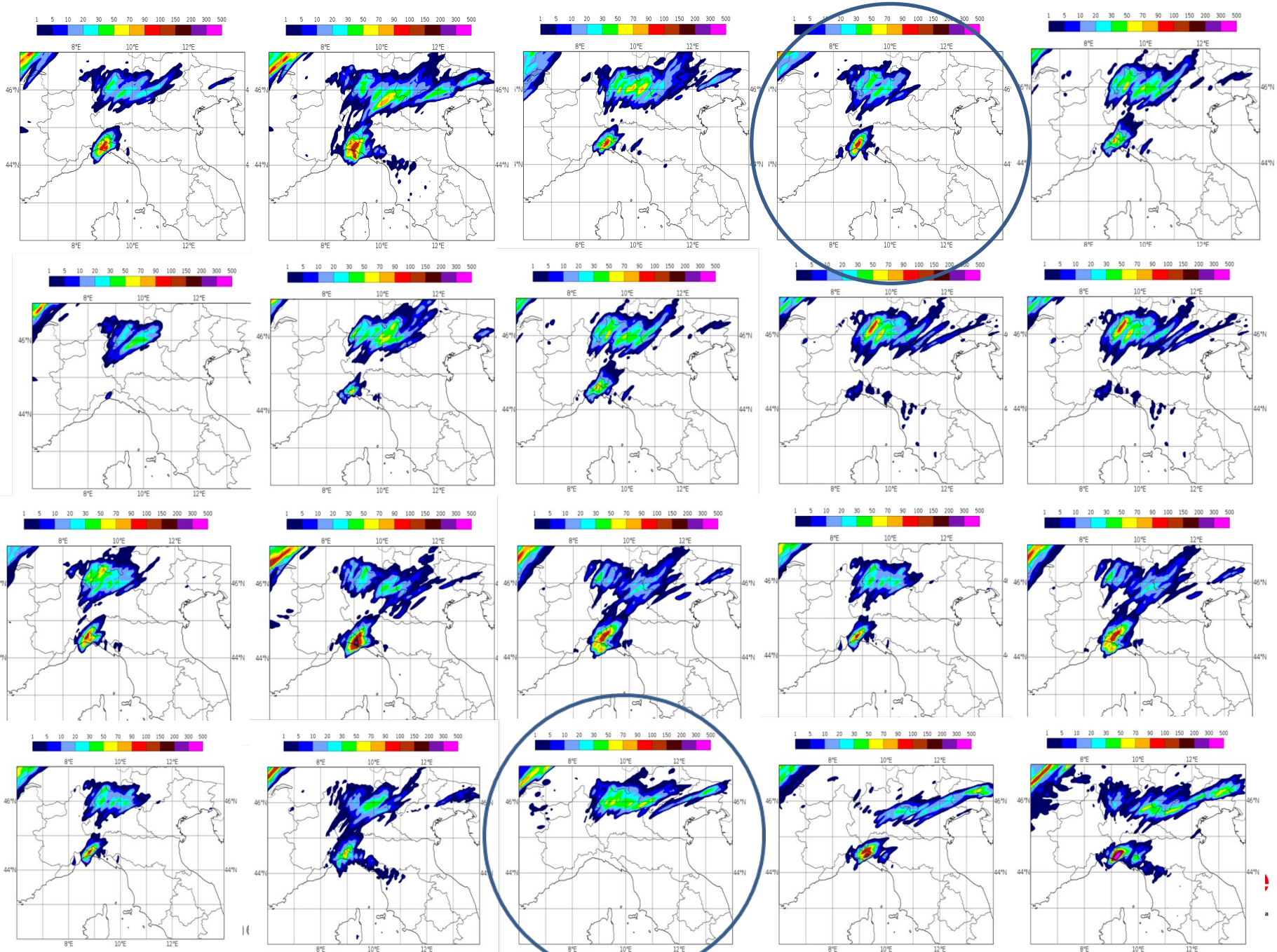
COSMO 2.8 km

agenzia prevenzione ambiente energia emilia-romagna

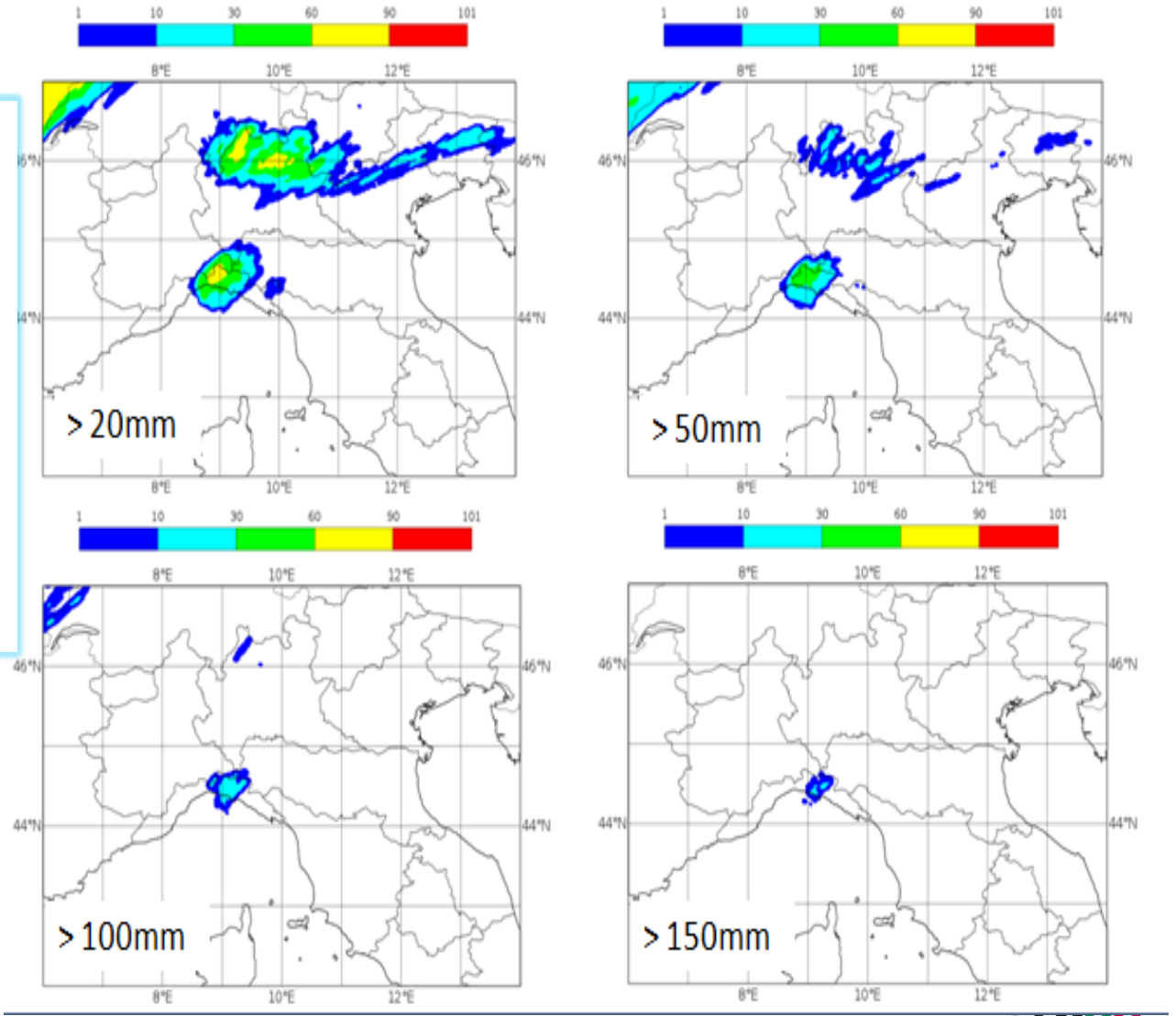
COSMO-IT-EPS run 9 ottobre 12UTC +00-24



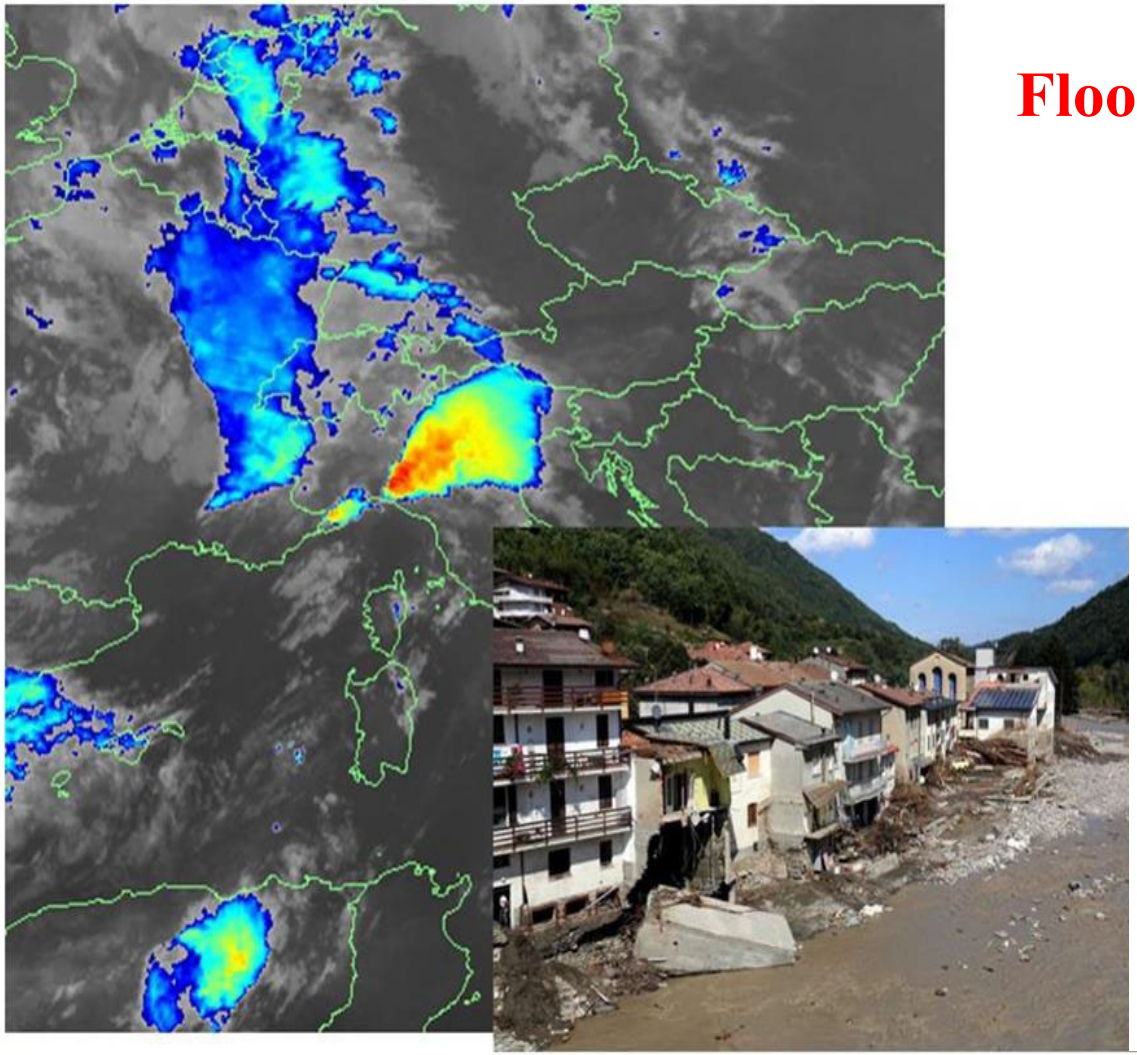
COSMO-IT-EPS run 9 ottobre 12UTC +00-24



Very good performance of The km scale ensemble



Flood event Piacenza 13-14 September 2015



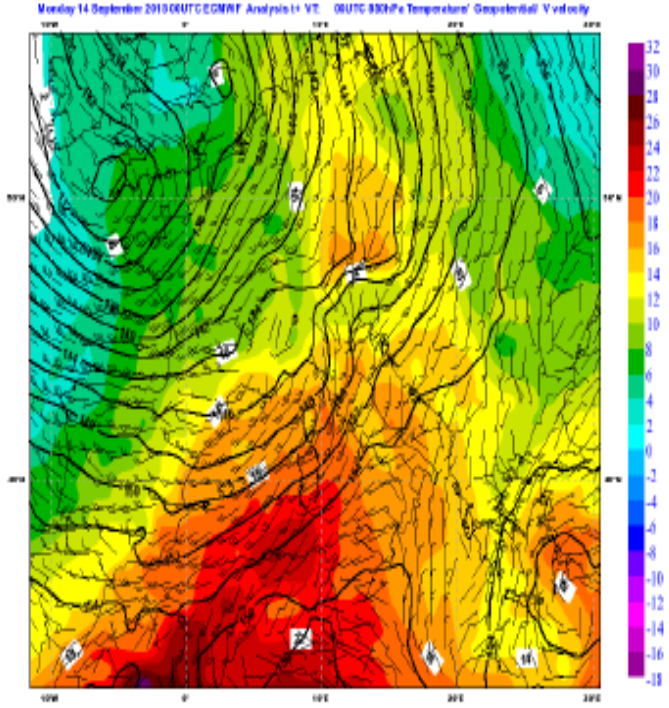
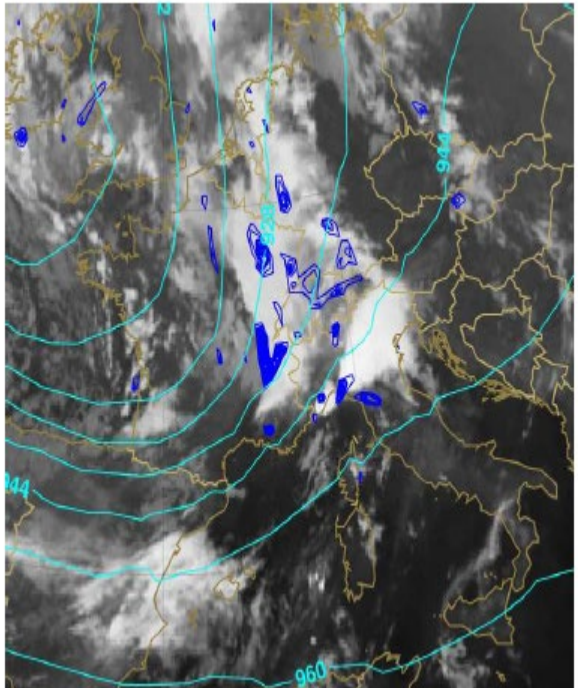
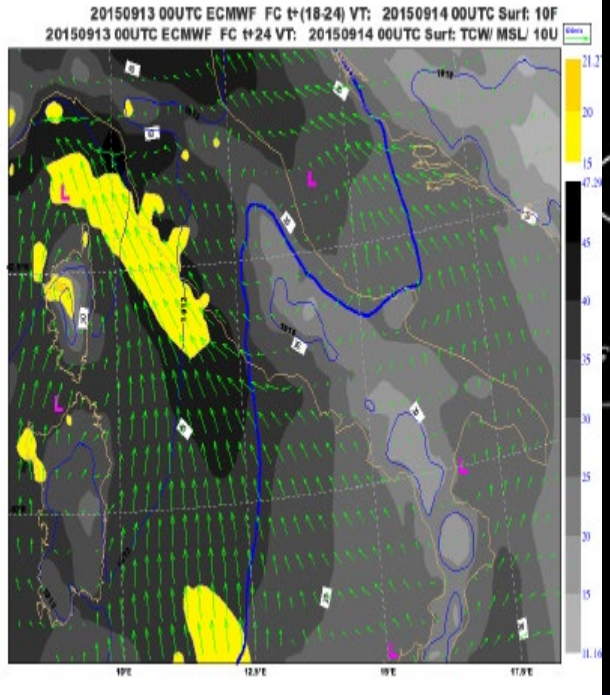
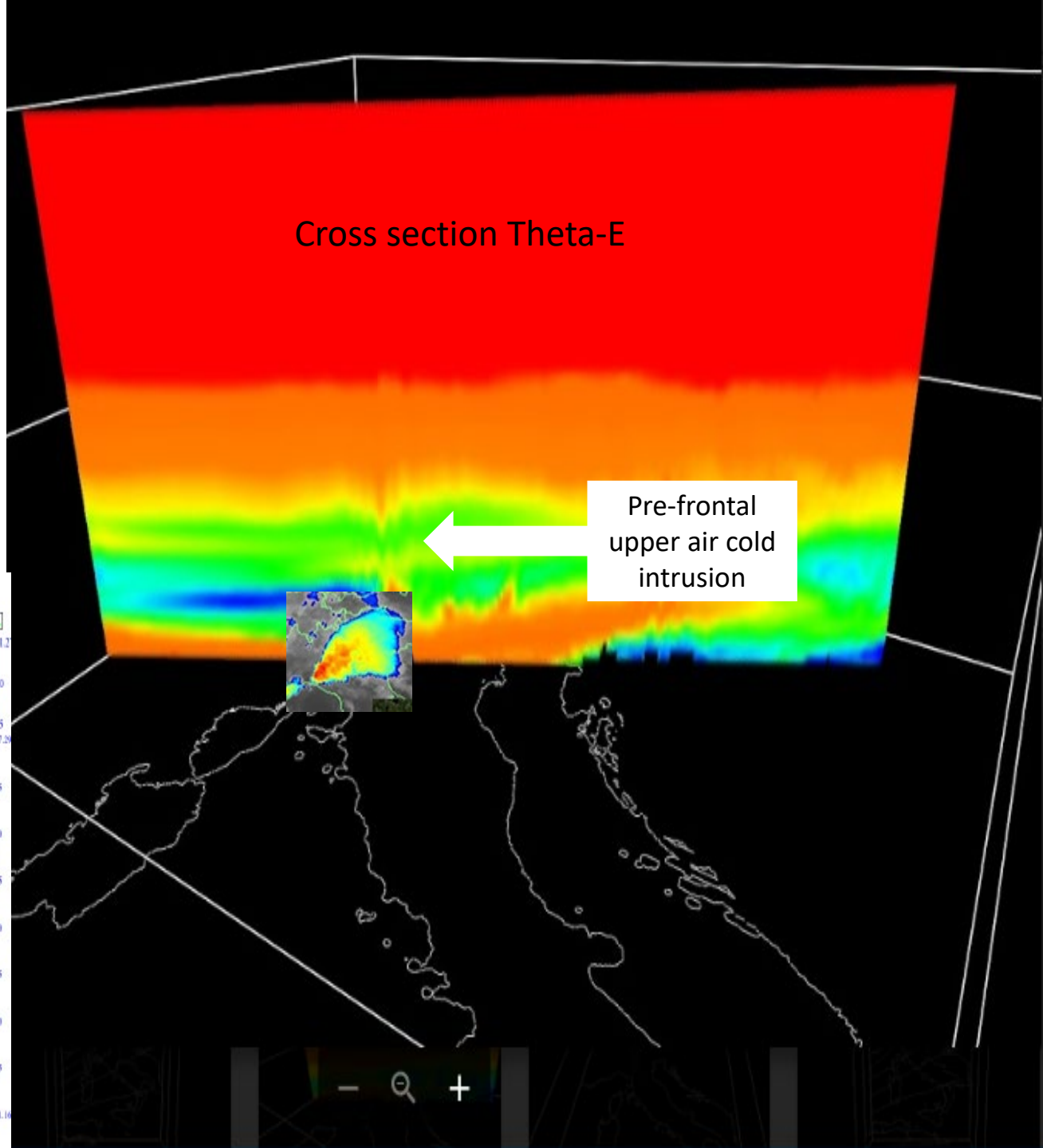


Fig. 1a - Immagine da satellite che mostra il fenomeno convettivo che ha dato luogo, nei giorni 13-14 settembre 2015, una importante alluvione lampo (flash flood) sulla Val Nure, in Emilia-Romagna.

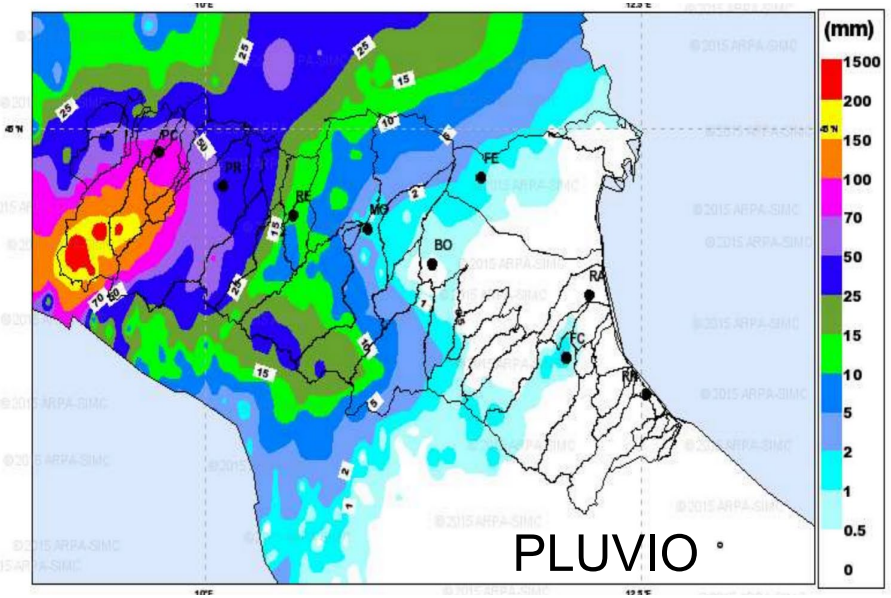
From Arpae-Simc event report, 2015



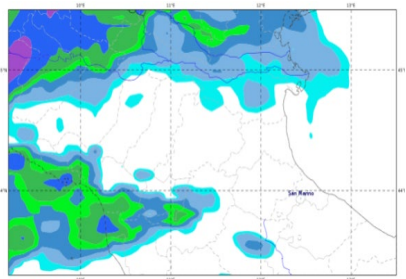

20150913 00UTC ECMWF FC t+(18-24) VT: 20150914 00UTC Surf: 10F
20150913 00UTC ECMWF FC t+24 VT: 20150914 00UTC Surf: TCW/ MSL/ 10U


Cross section Theta-E
Pre-frontal upper air cold intrusion

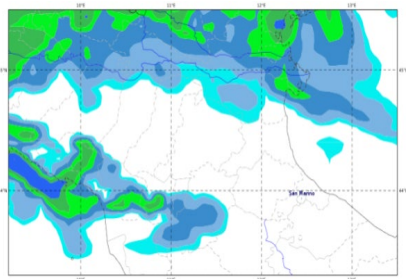
13 Sept 21:00- 14 Sept 03:00



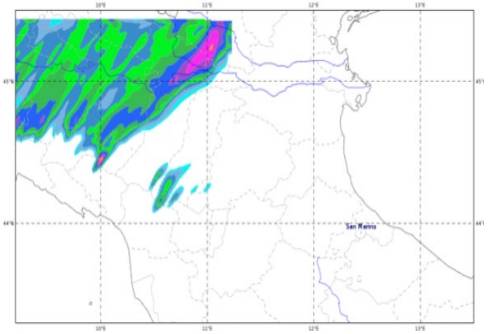
COSMO-I7Ope



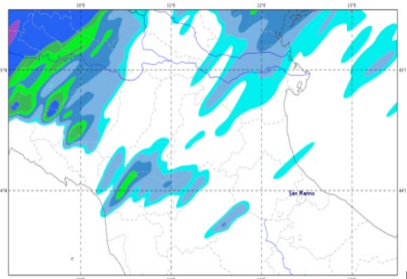
COSMO-I7Hind



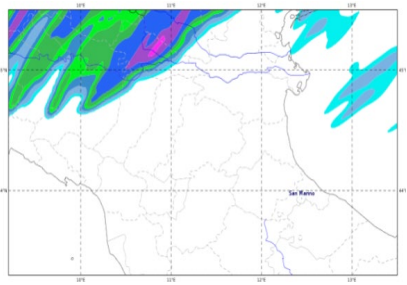
COSMO-I05 in I2Hind



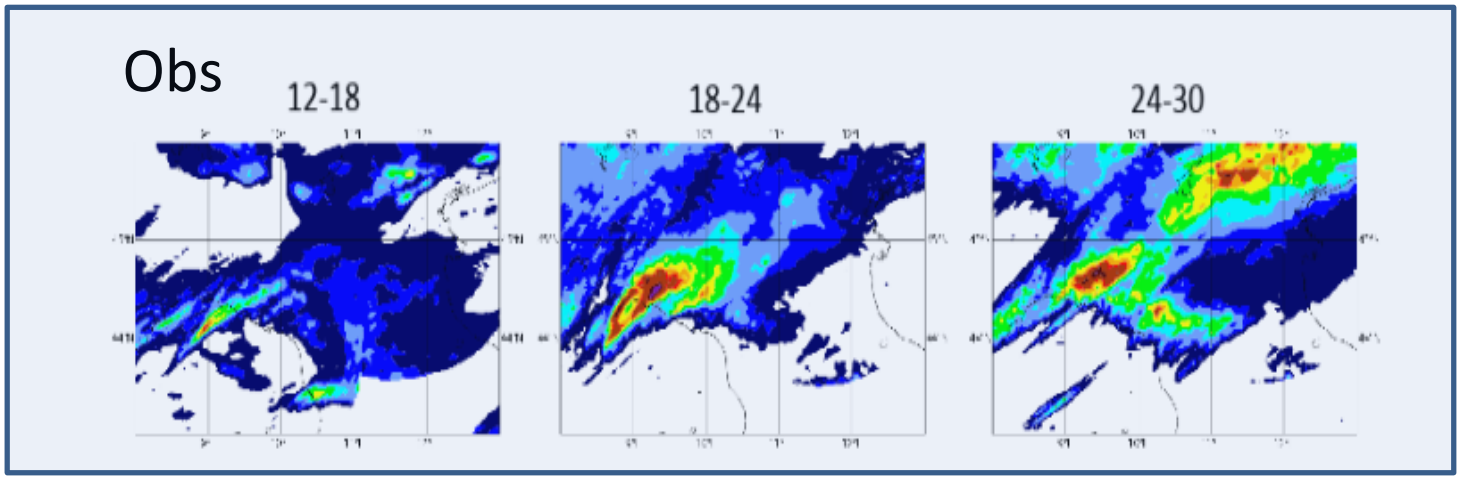
COSMO-I2Ope

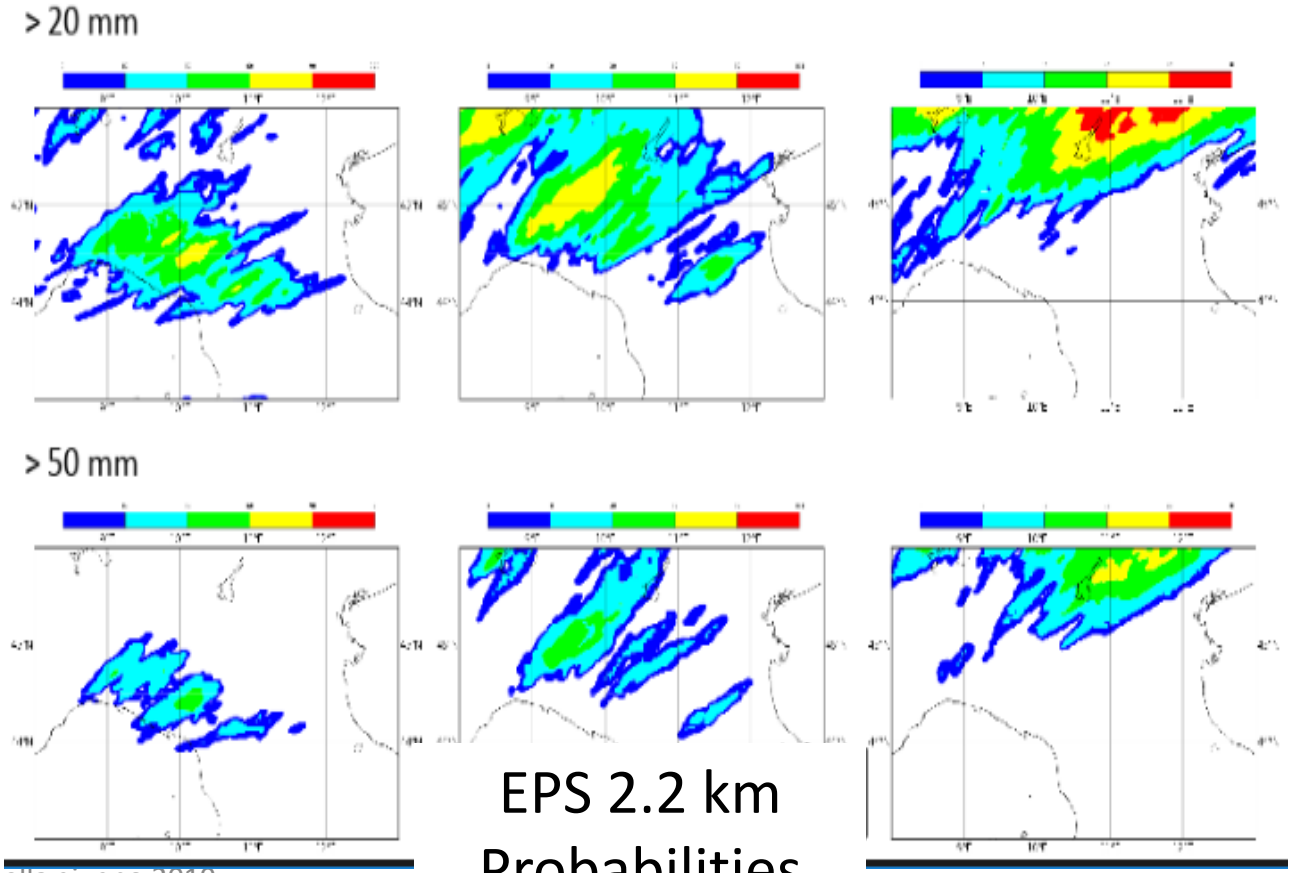


COSMO-I2Hind



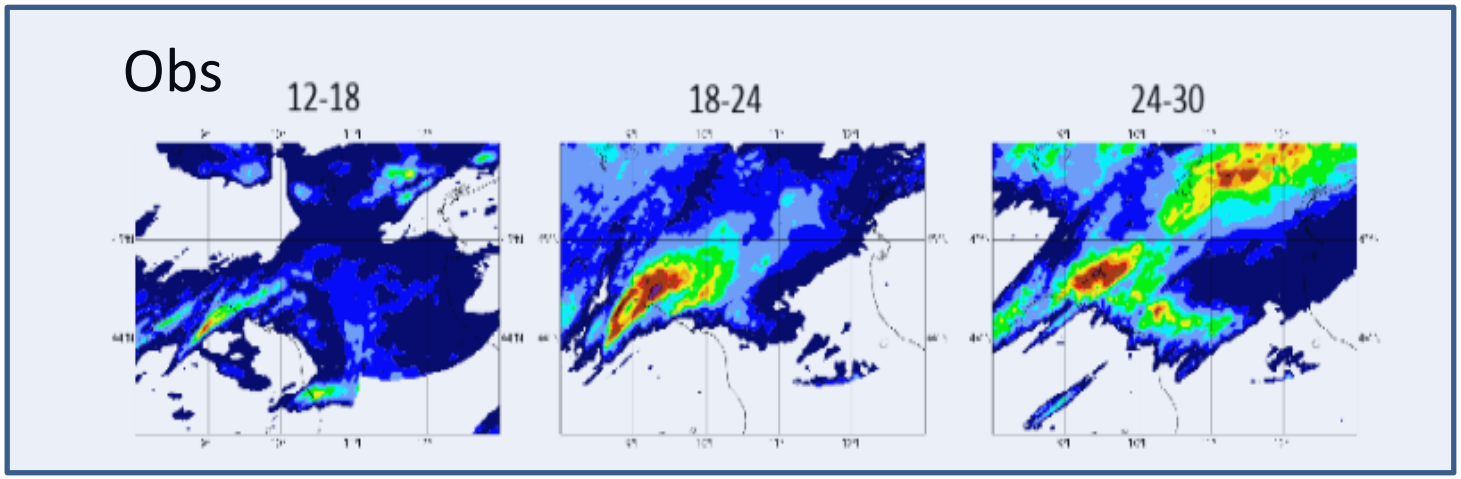
arpae
agenzia prevenzione ambiente energia emilia-romagna





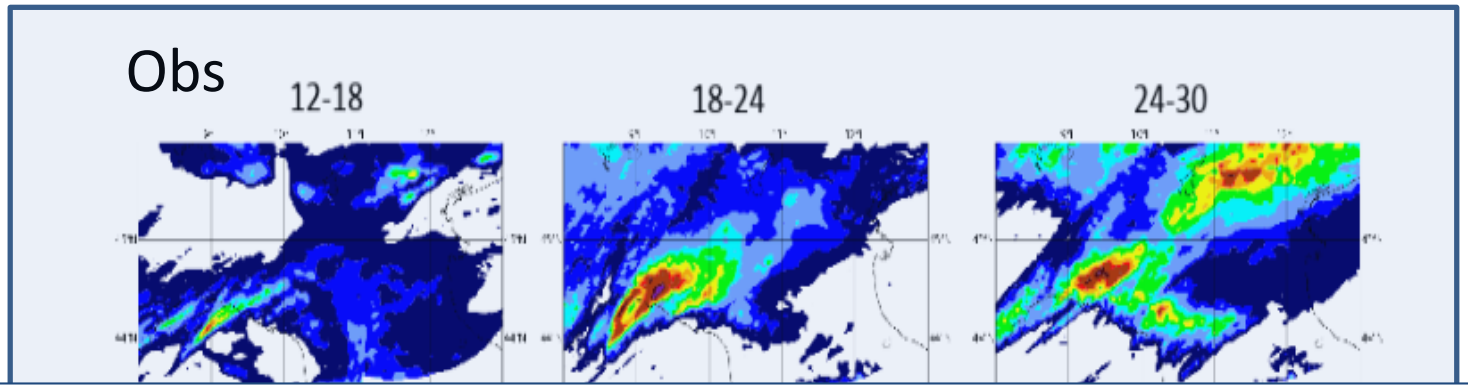
EPS 2.2 km
Probabilities

arpae
agenzia prevenzione ambiente energia emilia-romagna

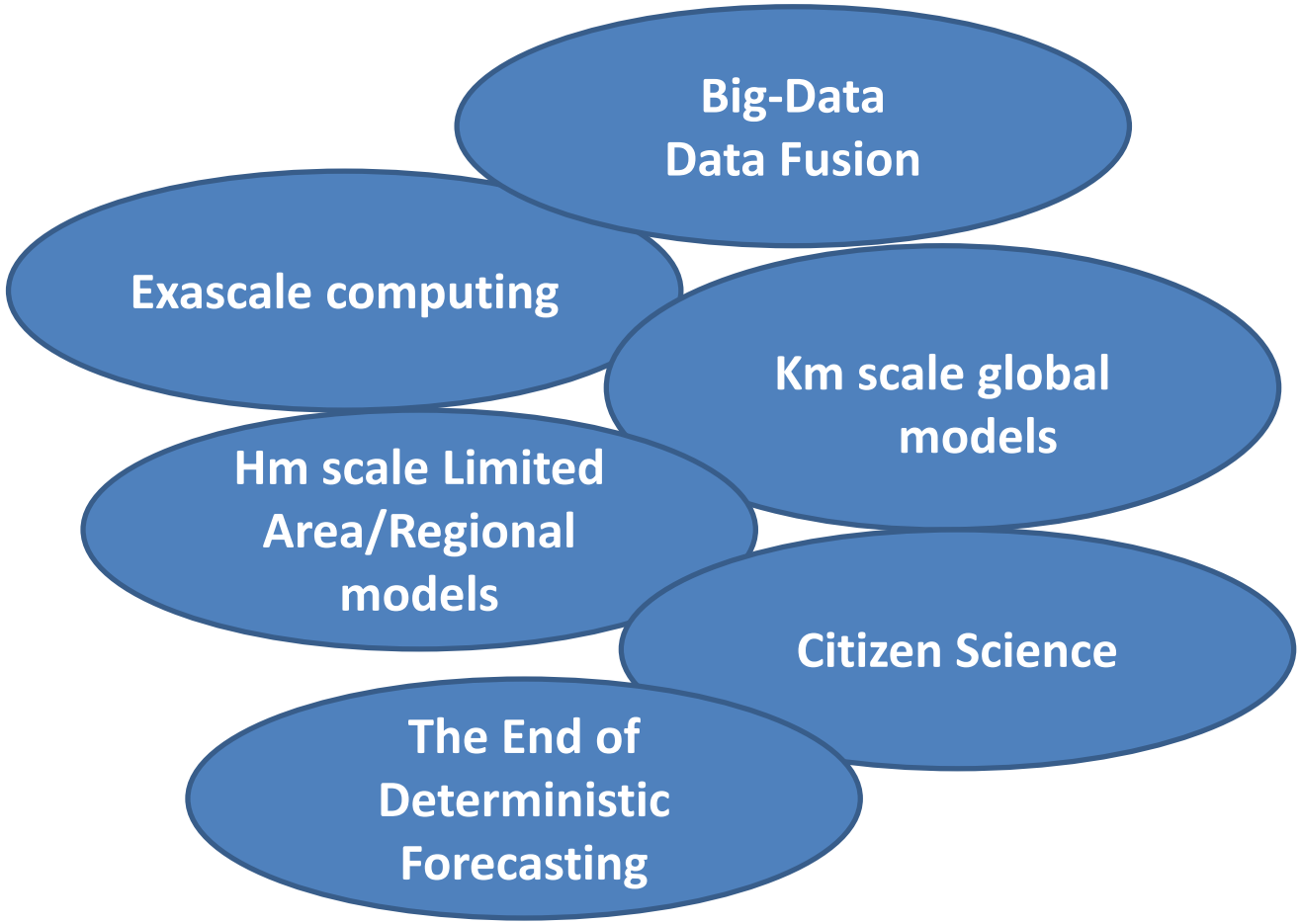


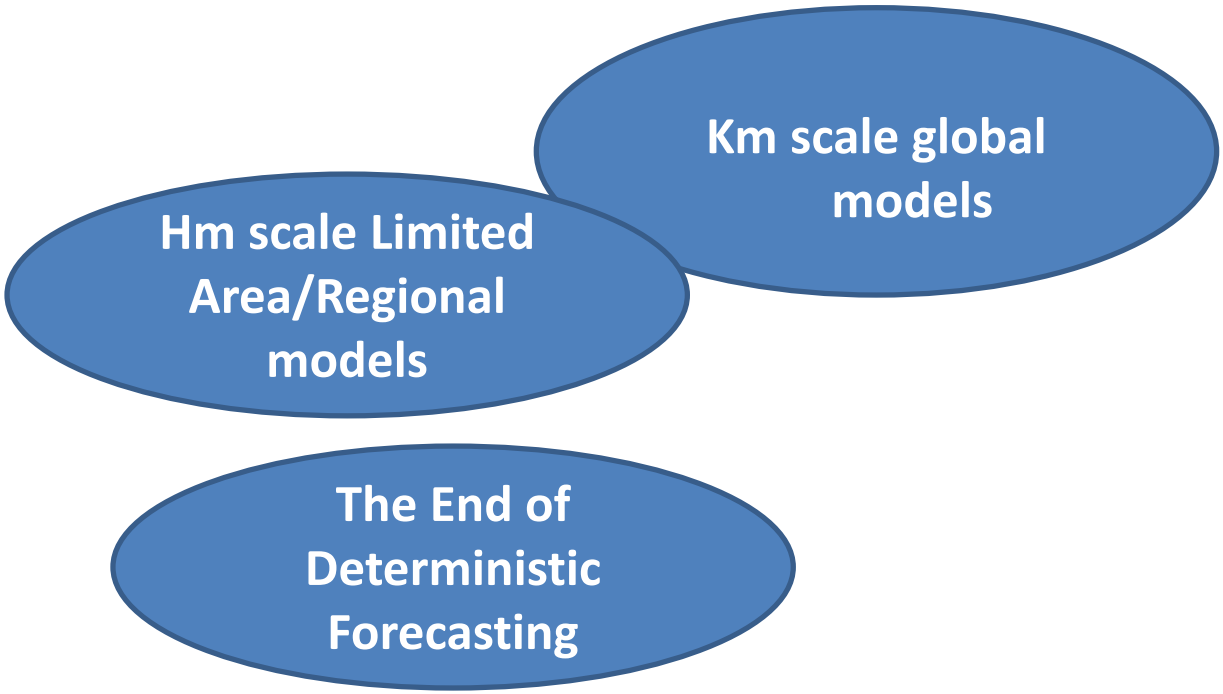
In questo caso il modello non sembra essere in grado di riprodurre in modo corretto la complessa dinamica associata alla supercella organizzata e persistente.

EPS 2.8 km
Probabilities



Se una tipologia di fenomeno non è riproducibile dal modello (errori sistematici, limiti nella fisica …) un ensemble basato su questo modello non è utile per aumentare la predicibilità di questo tipo di fenomeni.


Big-Data
Data Fusion
Exascale computing
Km scale global models
Hm scale Limited Area/Regional models
Citizen Science
The End of Deterministic Forecasting


Km scale global models
Hm scale Limited Area/Regional models
The End of Deterministic Forecasting

Come procedere?

Miglioramento dei modelli in senso deterministico

I modelli devono essere in grado di rappresentare i processi alla base dei fenomeni che vogliamo prevedere /analizzare.

I processi non rappresentabili dai modelli non possono essere «recuperati» con tecniche di ensemble.

Miglioramento dei sistemi di ensemble (techiche perturbative)

Continuare lo sviluppo di tecniche perturbative in grado di generare uno spread realmente rappresentativo dell'errore da associare alla previsione.

I sistemi dovrebbero essere alla stessa risoluzione di quelli deterministici.

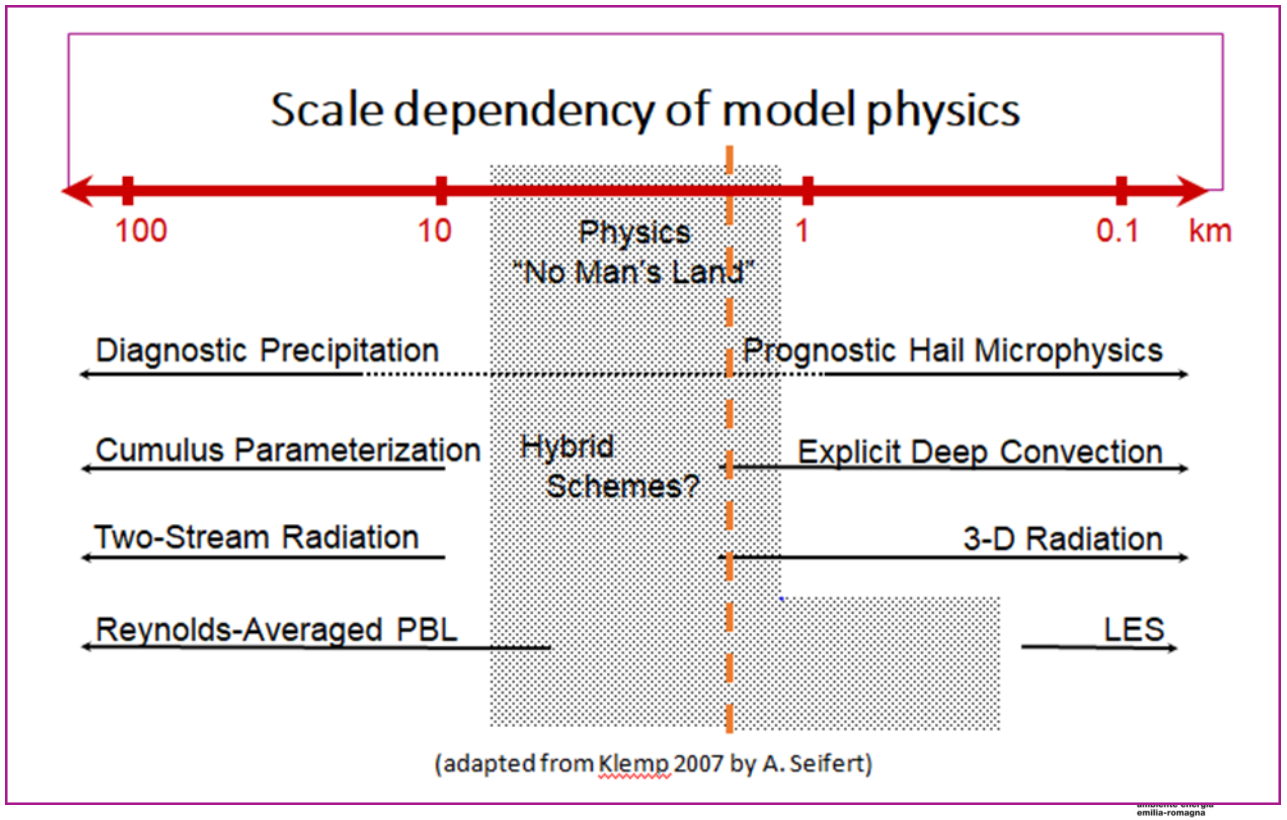
From: COSMO
Science Plan 2015-2020

The strategic elements are:

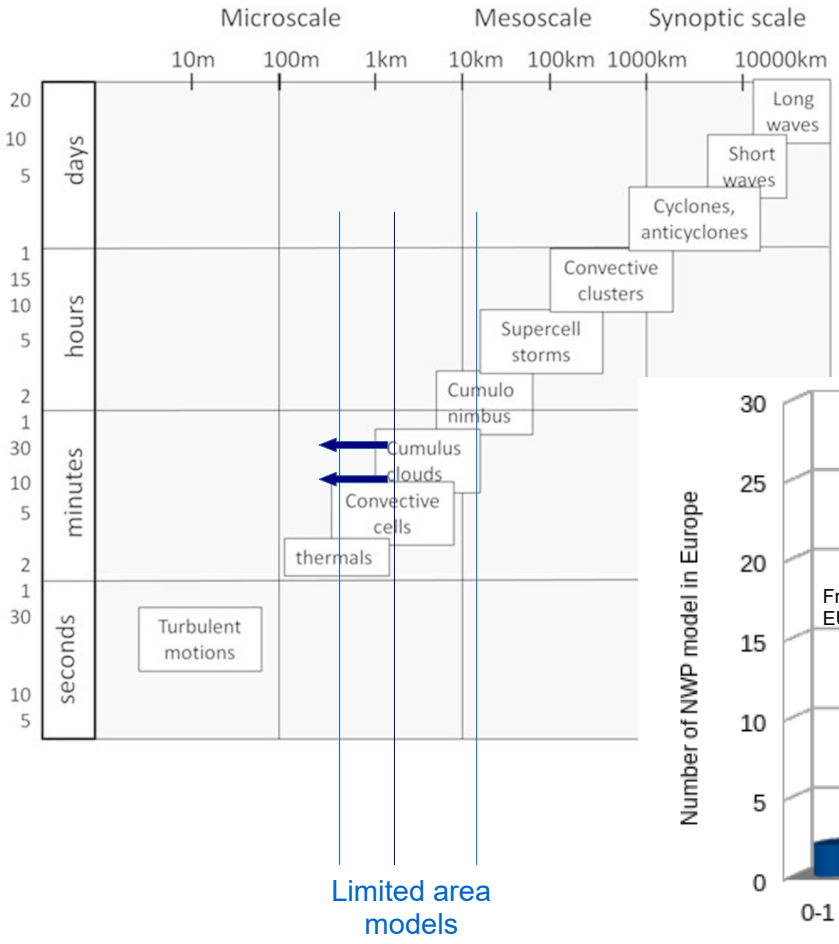
- conservative robust dynamical core;
- atmospheric and surface physics for convective scale;

Up to approximately 10 km resolution progresses have been somehow «linearly» related to technological advancements.

Yano et al. refer to these progresses as "straightforward extrapolation of techonologies for NWP".



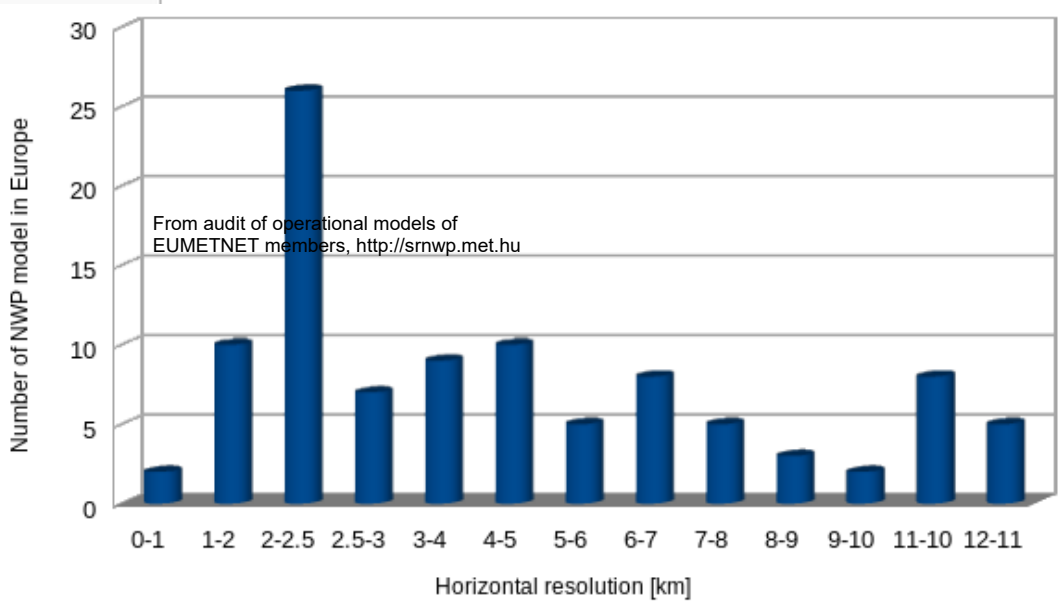
Km-scale challenges: parametrizations



We are in the shallow convection grey zone:

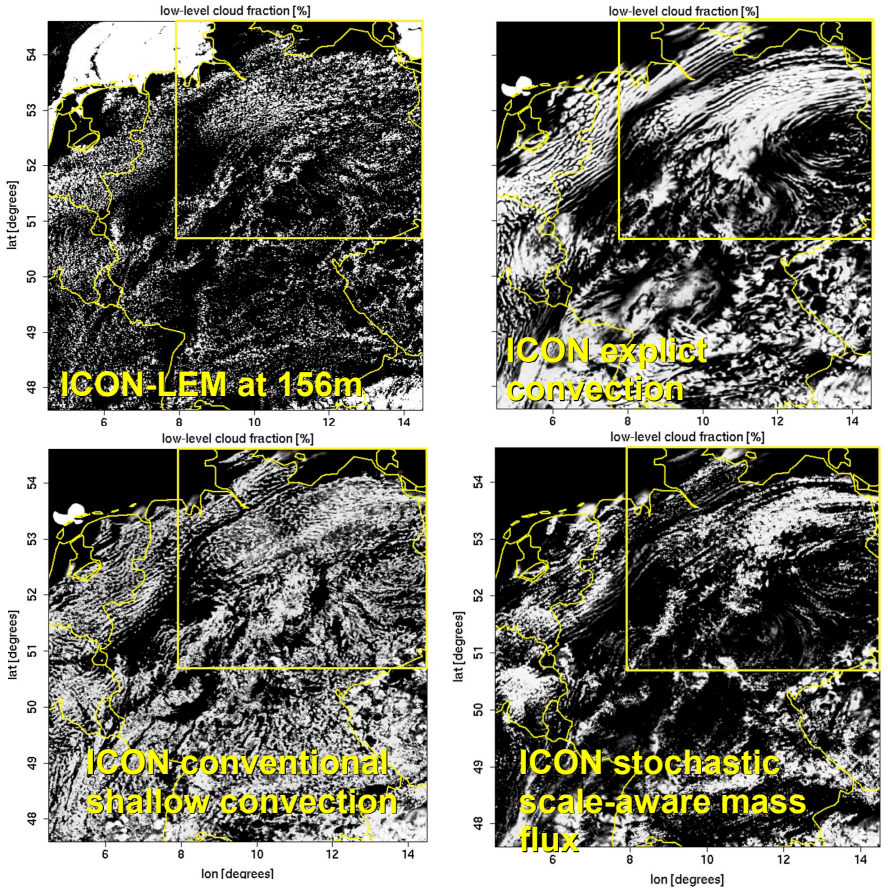
non-local eddies in PBL are partly handled by the model dynamics, but the parameterization of the vertical fluxes caused by these non-local eddies is still needed

Explicit convection needs scales < 100m



Slide from Ines Cerenzia

Shallow convection grey zone



Courtesy of M. Sakradzija

If explicit convection (no parametrization) applied at models at few km scale:

- high sensitivity to the numerics and applied diffusion → performance is case dependent
- better chance to catch extremes events (squall lines, propagating systems,..), but unrealistic features as grid point storms and instantaneous build up of CAPE
- PBL not enoughly mixed by the turbulence scheme only (effect on LCC)

If shallow convection scheme (mass-flux scheme) active:

- too mixed PBL (double counting some already resolved eddies)

Need for scale-aware mass-flux (Honnert et al. 2011, Sakradzija et al. 2016)

- handover between resolved and subgrid occurs at different lengths for momentum and scalar variances, for dry and cloudy PBL and in the ML and EZ
- coupling with turbulence and microphysics schemes

Slide from Ines Cerenzia

arpae agenzia prevenzione ambiente energia emilia-romagna

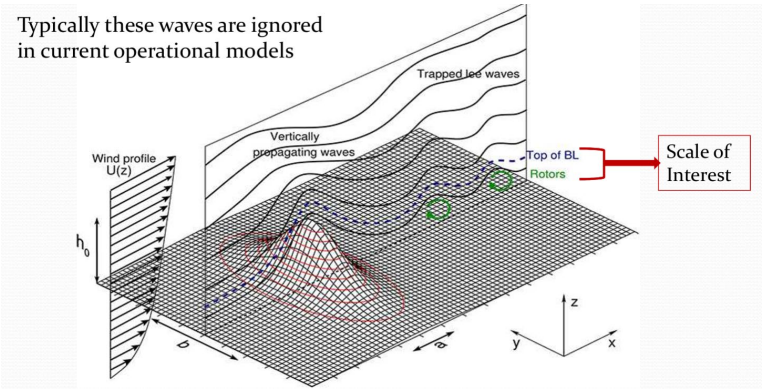
Km-scale challenges: parametrizations

Grey zone for other processes, not yet considered in NWP models:

- sub-mesoscale motions in the stable PBL: propagation or trapped gravity waves in association with small scale orography (e.g. Steeeneveld 2017, Teixeira 2017), non-local thermally driven circulations (e.g. due to surface heterogeneities, Mahrt 1995, 2009, Cerenzia 2017), ..

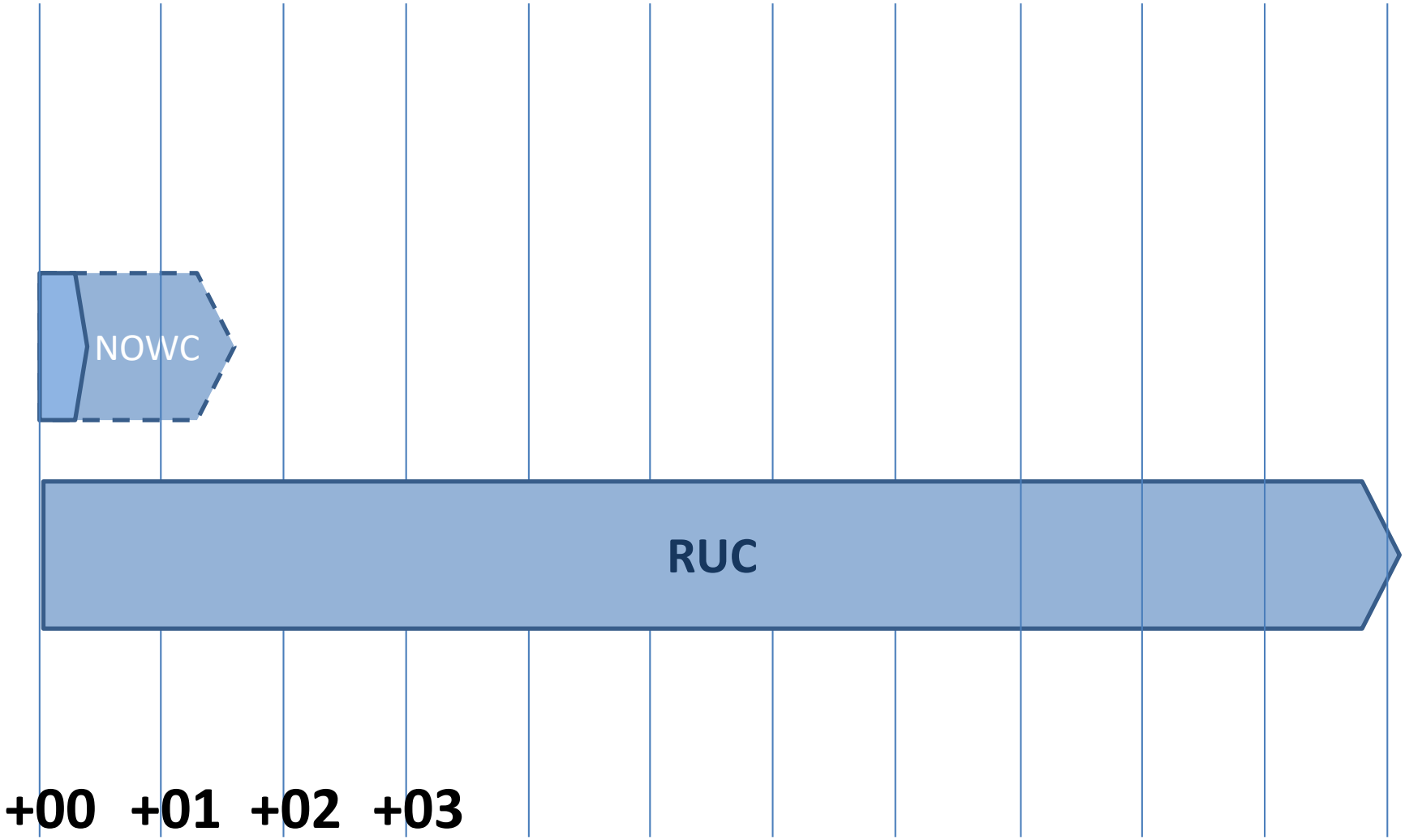
Scale-aware parametrizations have the potential to introduce real sources of drag in operational NWP as an **alternative to the artificial increment of drag** currently applied through:

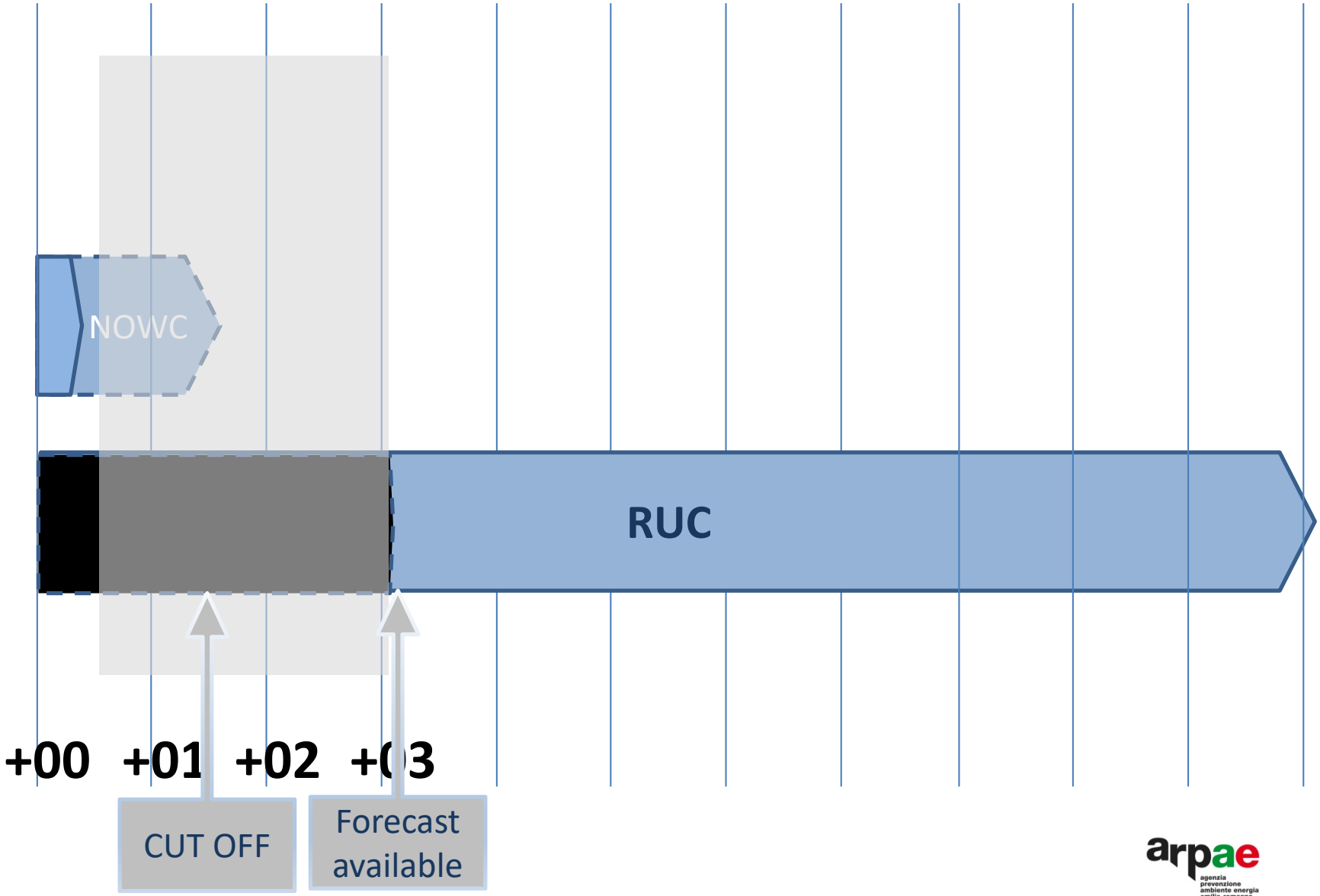
- long tail formulations (enhancement of turbulent diffusion in PBL). Currently without long tail formulations, the synoptic activity is too high, but with them the stable PBL can not be correctly represented.
- tuning of other subgrid sources of drag already parametrized (e.g. sub-grid scale orography scheme). Currently, drag has a high sensitivity to resolution: with increasing resolution the subgrid part decreases more than the resolved part increases (Sandu et al. 2016)

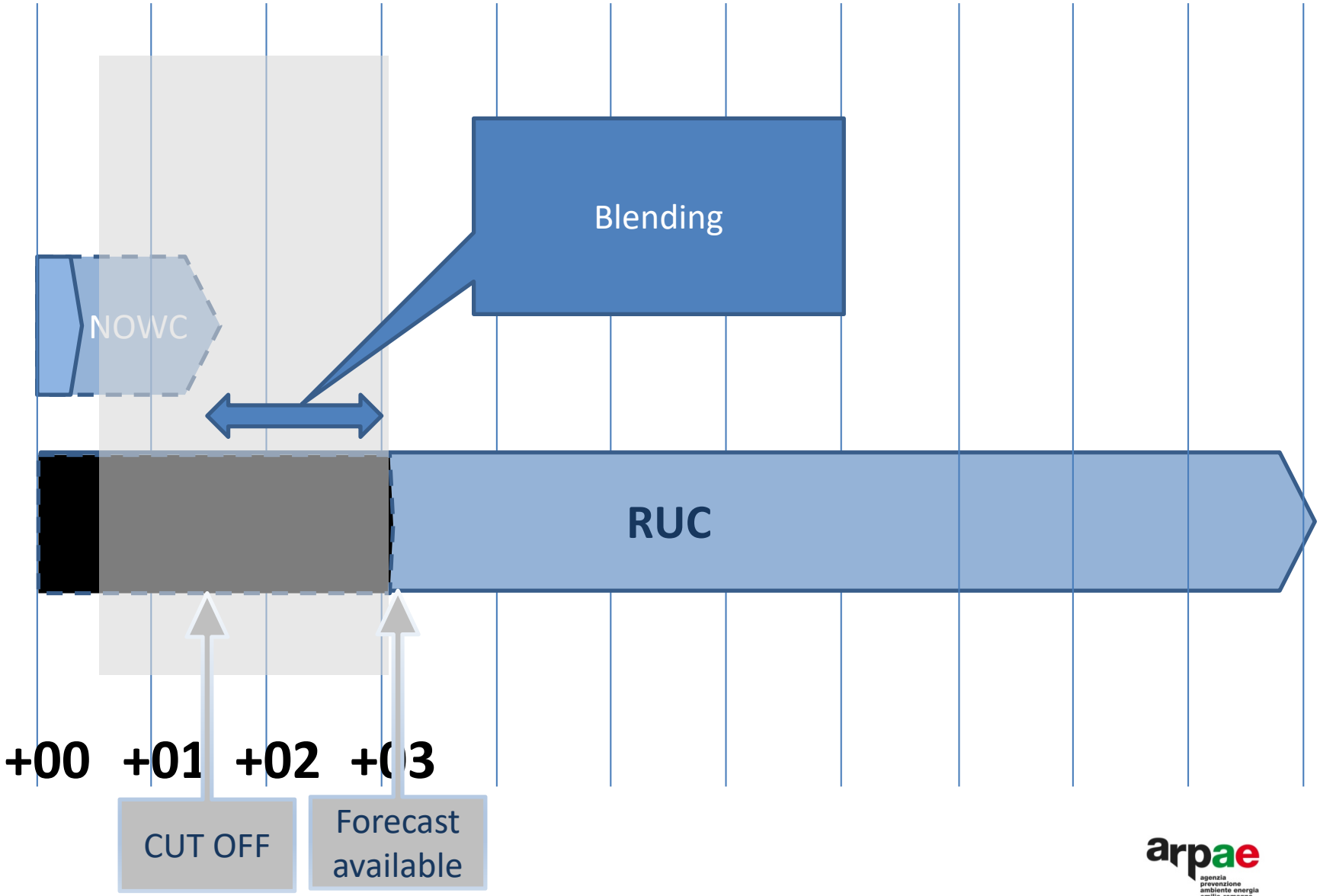


Predicibilità dei fenomeni a piccola scala può essere migliorata nel brevissimo termine, 6-18 ore, da sistemi di assimilazione dati idonei (il più possibile) alla scala del km:

- Special focus on very short range - RUC (Rapid Update Cycle) forecast
- Uso estensivo di varie tipologie di osservazioni
- Extended Nowcasting (blending techniques)
- Flow dependent BG error covariances


NOWC
RUC
+00
+01
+02
+03


NOWC
RUC
+00
+01
+02
+03
CUT OFF
Forecast available


Blending
NOWC
RUC
+00
+01
+02
+03
CUT OFF
Forecast available

From: COSMO
Science Plan 2015-2020

The strategic elements are:

- conservative robust dynamical core;
- atmospheric and surface physics for convective scale;

From: COSMO
Science Plan 2015-2020

The strategic elements are:

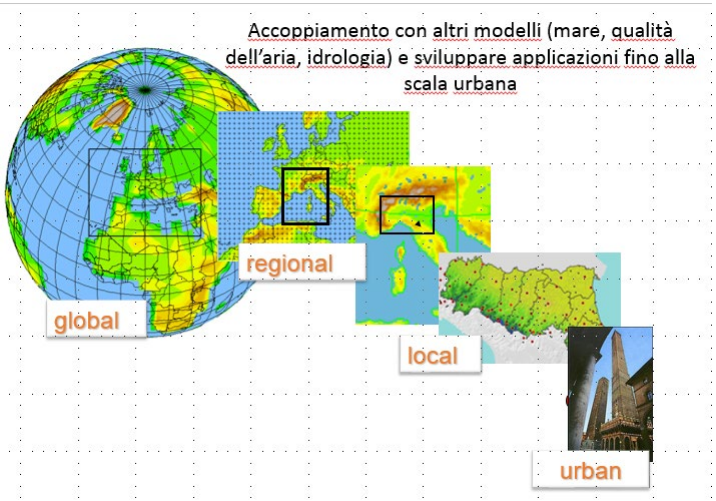
- conservative robust dynamical core;
- atmospheric and surface physics for convective scale;

- an ensemble prediction system for the convective scale;
- an ensemble-based data assimilation system for the convective scale;

The target is to develop metodologies to generate perturbations representative of all the source of "errors".
It is fundamental to have EPS with the right error/spread relationship also considering the always increasing importance of ensemble systems in the new data assimilation techniques.

From: COSMO
Science Plan 2015-2020

The strategic elements are:

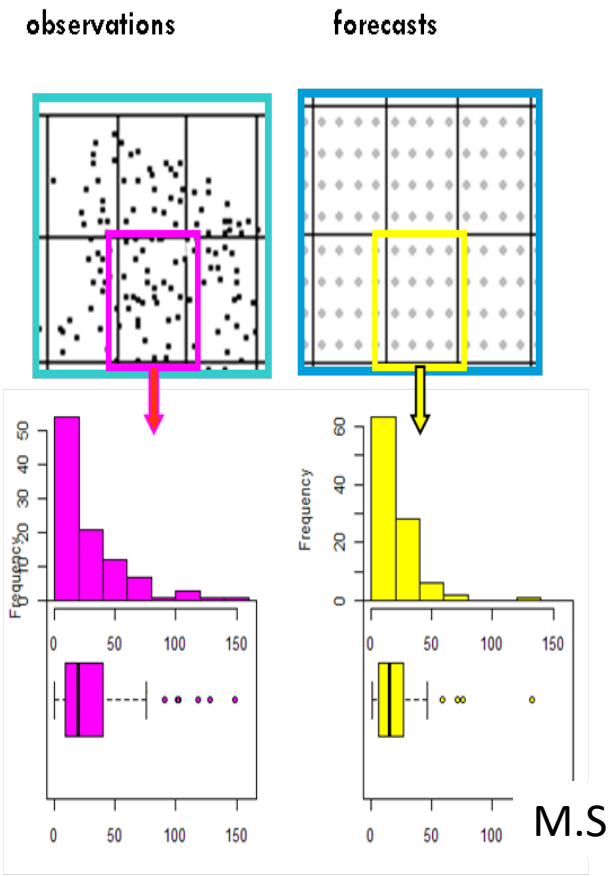


- conservative robust dynamical core;
- atmospheric and surface physics for convective scale;

- an ensemble prediction system for the convective scale;
- an ensemble-based data assimilation system for the convective scale;

- extension of the environmental prediction capabilities of the model;

Improve statistical interpretation of model output , both for deterministic and ensemble systems, by aggregating model cells with suitable spatial techniques,



From: COSMO
Science Plan 2015-2020

The strategic elements are:

- conservative robust dynamical core;
- atmospheric and surface physics for convective scale;

- an ensemble prediction system for the convective scale;
- an ensemble-based data assimilation system for the convective scale;

- extension of the environmental prediction capabilities of the model;

- a verification and validation tool for the convective scale;

M.S.Tesini

From: COSMO Science Plan 2015-2020
Management Summary

The strategic elements are:

- conservative robust dynamical core;
- atmospheric and surface physics for convective scale;

- an ensemble prediction system for the convective scale;
- an ensemble-based data assimilation system for the convective scale;

- extension of the environmental prediction capabilities of the model;

- a verification and validation tool for the convective scale;

- use of massively parallel computer platforms and emerging new (heterogeneous) architectures;

Science community agrees that at very high resolution models will make qualitative jump in accuracy, but this comes at a very high computing&data cost

"A change of paradigm is therefore needed regarding hardware, design of codes, and numerical methods"

km. Scale

Ensemble forecasting

Ensemble based DA

Earth Model systems

Climate applications

Technological challenges and priorities:

- **NWP models more scalable with new code design methodologies (efficient cooperation between Scientists developing the model in its Physics aspects and Computer Scientists making model code suitable for new computer architecture)**
- **New hardware base on low power processors**
- **Data distribution and data archiving**
- **Advanced data compression methods**
- **Use of new types of (less accurate but high density) data available thanks to new techologies as mobile phones or other low cost networks (strong links with big data science)**

Bauer, Thorpe, Brunet 2015

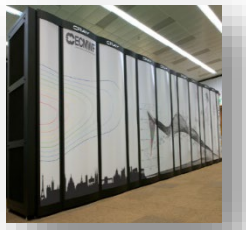
arpae agenzia prevenzione ambiente energia emilia-romagna

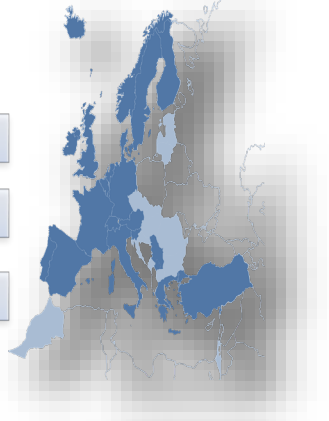
Weather & Climate "is" Big Data

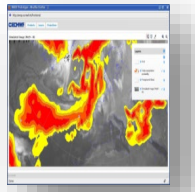
Growth factors of data volumes along forecast chain in next 10 years.

Courtesy of Peter Bauer

30x more data sent to customers per day in critical path







10x more observational data per day

2000x more model data per time step

25x more forecast product data per day in critical path

100x more data archived per day

Today: ~2 Pbyte per week!

Total archive: ~ 250 Pbyte

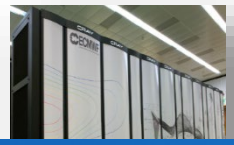
arpae agenzia prevenzione ambiente energia emilia-romagna

Weather & Climate "is" Big Data

Growth factors of data volumes along forecast chain in next 10 years.

Courtesy of Peter Bauer

30x more data sent to customers per day in critical path



RMDCN

10x more observatio data per d

2(m ti

Today: ~2

Total arch

Grazie !

arpae
agenzia prevenzione ambiente energia emilia-romagna

Accoppiamento con altri modelli (mare, qualità dell'aria, idrologia) e sviluppare applicazioni fino alla scala urbana